The Practice of

SILVICULTURE

BOOKS BY

RALPH C. HAWLEY

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SILVICULTURE

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PREFACE TO FIFTH EDITION

Practice of Silviculture was first published in 1921 and revised in subsequent editions in 1928, 1934, and 1937.

Eight years have passed since the last (fourth) edition of *Practice of Silviculture* was published. Much progress has been made during this period toward a better understanding of the principles of silviculture as they apply to the forests of North America. Increasing application of these principles is found in the woods.

In this fifth edition, *Practice of Silviculture* has been thoroughly revised, and many portions have been rewritten and enlarged to give expression to new knowledge and modern interpretations of old principles.

The book is prepared for use as a textbook for a two hour a week course running a half school year.

Lists of references at the end of the chapters are given so that the text may be supplemented by the assignment of additional reading, particularly if it is desired to expand the course. These reference lists have been brought up to date. When possible, in selecting the references, attempt has been made to list those that are most likely to be available to the student.

Technical names of the tree species mentioned in the text have been placed in a list in the Appendix. Sudworth's check list, with changes as approved by the U. S. Forest Service Tree Name Committee in January, 1940, has been followed.

R. C. Hawley

New Haven, April, 1946.

CONTENTS

CHAPTER I

GENERAL CONSIDERATIONS

Introductory. Silviculture may be defined* as the art of producing and tending a forest; the application of the knowledge of silvics in the treatment of a forest. Silvics deals with the fundamental laws underlying the growth and development of single trees and of the forest as a biological unit. It thus provides the scientific basis upon which the art of producing and tending a forest is founded. Silviculture applies information furnished by silvics to the production of forest crops, and develops principles of technical procedure for the scientific tending and reproducing of these crops. Finally, as experience increases, the principles of technical procedure may be amplified into detailed procedure for growing each tree species.

A recent article by Spurr (1945)† defines silviculture as the theory and practice of controlling forest establishment, composition and growth. Although this definition is considered less desirable than the one already given, it has the advantage of placing emphasis upon the efforts of man in relation to forest growth and development in contrast to the wild forest which may be established and pass through its full life history without interference by man and hence without the aid of silviculture.

In a broad sense silviculture is often considered as including both the scientific basis (silvics) and the application of silvics to the production of forest crops. Although the two subjects are thus closely related, they are best treated each in a separate book. There is already available an excellent textbook on silvics (Toumey and Korstian 1937). The present volume, as its name "Practice of Silviculture" indicates, does not include the field of silvics. An understanding of silvics is an essential prerequisite for intelligent practice of silviculture. Such knowledge is taken for granted in those who read this book.

A complete treatment of the art of producing forest crops should include not only discussion of principles and methods of technical procedures but also the details of silvicultural practice for all im-

* Unless otherwise stated, definitions of technical forestry terms used throughout this book are the same as given in *Forestry Terminology*. Society of American Foresters. 1943.

† References cited will be found at the end of each chapter.

portant tree species. Since in the United States of America the number of important tree species exceeds one hundred it is evidently impossible to cover all this field adequately in one book. Practice of silviculture as here presented covers the art of producing forest crops but does not take up the details of practice for each important species, other than to illustrate principles and procedures by concrete examples of application for individual species. American silvicultural practice is as yet in the developmental stage. Exact knowledge as to detailed procedures for producing crops of many commercial species is still lacking although for a few species reasonably complete information is available.

Unfortunately it is still true that on only a portion of the forest area in the United States has the production of forest crops been taken up as a business. Even on the great majority of these lands relatively few years have passed since such management was initiated. Ultimately, and in the not distant future, silviculture must be applied to all areas which are potential wood-producing lands, if this nation is to maintain in permanently productive condition one of its greatest natural resources — the forest. It is unnecessary at this point to discuss the causes which have operated to prevent general application of silviculture to forest lands in this country. Summed up, these causes are essentially of an economic nature and are gradually changing for the better with the passage of time.

A favorable factor is that silviculture can be practiced with a varying degree of intensity or refinement often making possible a start in crop production even under rather discouraging economic conditions. Simple applications of silviculture can be found on some forest lands in every part of the country. The number of such tracts is increasing and the quality of the technique used in crop production is improving. The words extensive and intensive are often used in this connection to evaluate the grade of silvicultural practice applied at a given time and place. Extensive application is correlated with a small expenditure per acre for cultural operations, for reproducing the forest areas cut over, and for protection of the crop; while conversely intensive application presupposes considerable investment per acre in establishing and caring for the forest crop. The amount and quality of the wood crop secured under extensive application of silviculture will be lower than under intensive methods.

The area of land in this country available for timber production was estimated in 1933 to be approximately 509 million acres.* Of this total 100 million acres of the best lands are suited for intensive crop

* The figures in this paragraph are taken from "A National Plan for American Forestry," *Senate Doc.* 12, 73d Congress, 1st Session.

production and 339 million for extensive crop production, whereas protection only should be afforded 70 million acres of land relatively unfavorable for crop production. It is estimated that about 110 million acres, 21 per cent of the total commercial forest area, are under some technique of timber crop production although not over 30 million acres have even fairly intensive management in addition to fire protection. Undoubtedly since 1933 the areas of private forest land managed for forest crop production have increased.

Following the application of either intensive or extensive silviculture there should be an improvement over the production accruing without any practice of silviculture. Unmanaged or mismanaged forests, like poorly cared-for farm lands, do not produce forest products of the kind, in the amount, or of the value which might be grown. Silviculture, by properly tending the wild forest and establishing new forests on open areas, increases productivity. How this is accomplished is briefly outlined in the next section.

Production in Managed and Unmanaged Forests. The unmanaged or mismanaged forest shows lower production than the managed forest, owing to one or more of the following defects:

1. Species inferior in some respect to those that might be growing occupy part or all of the area. Such species are the weeds of the silviculturist. They flourish at the expense of better varieties. Silviculture must eliminate and keep inferior species from reappearing. "Inferior," as here used, is a relative term, since a species may be the best tree to grow under one set of circumstances and a forest weed elsewhere. Inferior species are particularly apt to appear after disturbance in the forest cover due to such agencies as lumbering and fires. Even the virgin forest is likely to contain one or more inferior species, since the factors that enable a tree species to establish and maintain itself in competition with other species are not necessarily those that determine its silvicultural desirability. Hence opportunity exists for the forester to improve upon nature in regulating the composition of the managed forest. It is conceivable that on a given site some temporary forest type will prove more desirable than the climax type. If so, effort should be made to develop and maintain this type. In other words, the virgin or climax forest is often not the goal in forest crop production. Knowledge as to all stages of forest succession leading toward the forest climax is important as an aid in predicting the natural development of a given forest area. The goal, however, is the development and maintenance of a commercially productive forest which may be or, more likely, may not be identical in composition to the climax forest.

2. The forest is too sparsely or too densely stocked with trees for the best results. Either of these two extremes is detrimental, both having the final effect of reducing the value of the crop produced. Too sparse stocking results in part of the area being unproductive during a portion, at least, of the life cycle of the forest, or results in raising branchy trees yielding poor-quality timber. Too dense stocking leads to stagnation of growth and a small final crop. Silviculture should provide and maintain throughout life enough trees to stock the area properly and no more.

The environment under which a tree grows strongly influences the properties and qualities of the wood. One factor in the environment readily controlled by silvicultural operations is the density of the forest cover. Wood from trees grown in an open stand is unlikely to have the same properties and qualities as that obtained from trees grown in a fully stocked stand. The silviculturist may produce, by controlling through cuttings the density of the stand, wood of suitable quality for the product wanted.

3. Part of the area which should be forested is without forest. Fires, logging, and clearing for agricultural use of lands which are unsuited for that purpose are chiefly responsible for this situation. The deforested condition may be only temporary — natural seeding finally stocking the open lands — or it may be, for all intents and purposes, permanent, because of the extent of the deforested lands and lack of trees to reseed them or the condition of the lands. Silviculture must prevent the creation of further open areas and restock those now existing.

4. Crooked, misshapen, and defective trees (even though of valuable species) are apt to accumulate in the forest not under silvicultural treatment and retard the development of better individuals. These trees should be removed.

5. Losses caused by agencies such as insects, animals, fungi, fire, and wind are sustained, often without salvage of the damaged material and without efforts to check the injury from being spread to adjacent parts of the forest. Silviculture must afford protection to the forest.

6. Owing to mismanagement and lack of protection the forest may cease to protect properly the site on which it grows and lands adjacent to or directly related to the forest. The forest floor may be destroyed and the soil eroded or baked and cracked open, to the detriment of the physical factors of the site. Lands depending upon the forest for protection may be eroded or covered with infertile soil and debris. Navigation on the lower reaches of streams rising in the forest may

be interfered with, reservoirs may be filled, and irrigation works may be rendered useless. Silviculture must prevent injuries to the site and also to lands and industries dependent upon the forest for protection.

As a result of these various defects the production, quantitatively, qualitatively, and financially, of forest products figured on an acreage and a time basis is less than it might be.

The Purpose of Silviculture. The purpose of silviculture might then be summed up as the creation and maintenance of such a forest as will yield the highest returns in a given time. Such a statement should be qualified, because the object which the owner of a forest has in view will be the controlling factor in the silvicultural work. The statement should be modified to read: The purpose of silviculture is the production and maintenance of such a forest as will best fulfill the objects of the owner. Where the forest must be handled with the object of furnishing protection to other property, silviculture not entirely in harmony with the owner's desires may have to be applied, but this is exceptional. The objects of the owner may be diverse. The essential thing is that the object for which silviculture is applied should be known and the treatment shaped to the accomplishment of the desired end.

The commonest object for which silviculture is practiced is the production of wood crops to secure the highest returns, financially, in a given time. Protection of watersheds and lands adjacent to the forest, conservation of wild life, or development of the best esthetic effects are other objects that may be of primary importance with certain owners. This book treats primarily of the production of wood crops and only where otherwise stated has it any other objective in view.

It must be understood that good silviculture requires the acceptance of a long-range viewpoint that recognizes the necessity of building up and maintaining a permanent forest — in other words working for the good of the forest as an entity itself. This involves operating in such a way that soil productivity is not impaired and that the health of the forest and its safety from destruction are preserved. Two contrasting goals can be recognized: (1) management on a biological basis to ensure protection of the site and preserve the forest, or (2) management on an economic basis for timber production of the greatest volume and highest quality. Management on a biological basis has sometimes been termed "following nature" and, as this phrase implies, disturbs in its operations existing forest conditions and natural development as little as possible. Cuttings are so light as

to make only small openings in the forest canopy. In this way the development of the forest toward the climax association is maintained and encouraged. The composition of the climax is ultimately attained. In the opinion of its advocates this so-called approach to nature's methods provides the ideal forest and conserves the site. They overlook, however, the fact that nature's method is one of chance rather than of systematic principle and does not necessarily guarantee either that the site will develop into and remain in the most productive condition or that the species occurring in nature's forest will provide the most desirable forest composition.

"Following nature" should indeed result in keeping areas so treated permanently in forest. But usually this can be accomplished by other methods. Since just as good or better results can in the great majority of cases be secured by management on an economic basis there is little excuse for slavishly "following nature" in the practice of silviculture. It is true that the forester cannot work too radically against natural forces. For example it would be the height of folly to attempt to plant the bare sand plains of the Lake States with redwood. Climate is the principal controlling factor in the growth of tree crops, and nature must be followed to the extent that no attempt be made to grow species in climatically unfavorable environment. Within this limitation there is on most sites ample opportunity for improving upon nature as respects the composition and character of the crop produced.

Even today there is confusion as to just what "following nature" means and requires. In most extreme form "following nature" may be interpreted as working toward the climax forest association with maintenance of the same composition as a goal. A more sensible interpretation of the phrase would mean simply the growing of species, either native or exotic, suited to the site (climatically and otherwise) and growing these species in either pure or mixed stands not necessarily of climax composition. A species suited to the site may even be an exotic, though thorough investigation and even long-term trial may be needed to settle the fact of suitability.

Experience in agriculture indicates that considerable departures from nature can safely be made, even to the extent of introducing new species of plants, when attention is given to securing the correct climatic environment. How would we obtain food for our population if agriculturists confined themselves to producing only the crops that nature would establish and maintain upon the land?

Just as in agriculture, so in the application of silviculture, management on an economic basis for timber production should be the rule.

The silviculturist will on the whole find less opportunity and need for such numerous and wide deviations from natural conditions and species than the agriculturist has. The former cannot afford to practice crop production so intensively as the latter, and usually his crop occupies the same ground for many decades in contrast to one-year use by agricultural crops. Successful practice of silviculture requires that detailed knowledge be available as to the trend of natural development toward the climax forest that may be expected on a given area. Only when so equipped can the silviculturist determine the details of management and the nature of the crop which should be grown. He attempts to exercise a controlling influence upon natural processes and to mold the forest into the form and composition best suited to meet the purpose of management.

Management on an economic basis with the goal of highest financial returns has comparatively seldom, even in the long-managed forests of Europe, been carried to such an extreme as to disregard the correct biological basis sufficiently to curtail production radically. The instances where this has occurred have been chiefly in connection with the artificial introduction of species on sites climatically unsuited for their normal development. Practice of silviculture in the United States can avoid the errors of this sort made elsewhere.

In application silviculture will strike a compromise somewhere between a close following of nature and rigid adherence to the economic basis. However, products of high economic value, as contrasted to nature's crops, must be the dominating objective in forestry as well as in agriculture. These usually cannot be secured by closely "following nature."

How far deviation from nature can safely be made to take advantage of economic gains must be learned by local experience on the ground. Success in maintaining a healthy, vigorous forest while growing profitable crops is the best evidence of silvicultural skill and knowledge. As a general rule, the skillfully managed second-growth forest differs widely from the climax association, being more productive, more vigorous, and safer from injury. In exceptional cases, where management on a too rigid basis of economic use threatens to destroy the forest or seriously reduce its productivity, a closer return to nature is indicated.

The Field of Silviculture. When viewed broadly the field of silviculture is not only to produce individual forest crops but also, while so doing, to build a permanent forest which can continue indefinitely to satisfy the objective of management. The tool which the silviculturist has for building the forest is primarily cutting,

although constant protection is essential. Throughout the life of each crop, both during the period of early treatment and that of regeneration, cuttings are made which vitally affect the structure of the forest. It is important to understand the long-time, cumulative effect of cutting operations in building a forest.

Cuttings affect the forest outwardly by the method of arrangement of the trees that are left standing. This is known as forest form or structure and is best indicated by a profile of the tree crowns in the forest. The two most common types of tree arrangement are the evenaged and the unevenaged: in the former the trees on an area are all of the same age or at least of the same age class; in the latter trees of at least three age classes occur on the area. Since a forest (unless it is a small woodlot) is seldom considered as just a single unit for cutting operations, the arrangement of age classes finds separate expression within each stand, of which there may be few or many, within a single forest. Arrangement of ages in a forest, even when the evenaged arrangement is employed within the individual stands, can be made exceedingly irregular by keeping the area of each stand small and by maintaining a wide variation in age between adjoining stands. The form or structure of the individual stand is affected directly by the proportion of the mature timber removed; all, for example, in clearcutting, or a small part in the selection method. This determines the age-class arrangement of the trees, best observed in a vertical profile through the stand.

The virgin forest may be evenaged though the unevenaged form is more usual. Even when unevenaged, the virgin forest, if composed of shade-enduring species as it is likely to be, appears quite regular in form, many of the younger trees being nearly equal in height to the older trees. Variation in rate of height growth depending on age explains the relatively even forest structure of virgin forests. The young trees with fast growth rate push up rapidly, somewhat helped by side crowding, and finally gain approximately the level of the old trees whose height growth has been for years practically at a standstill. The managed forest kept by frequent cuttings in unevenaged form should furnish a better example of this type of structure than the virgin forest.

A virgin forest of light-demanding trees will usually be relatively evenaged with patches of reproduction where openings in the old stand have accidentally occurred.

In addition to arrangement of trees of the different ages, such points as the species in the stand, the method of their mixture, the proportion of trees of seed and coppice origin, and the quality of the

individual trees are all affected by the cuttings and serve to characterize further the structure of the stand and forest.

The form or structure of the forest is determined not only by structure of the individual stand but also by (*a*) the size and shape of the individual stand areas and (*b*) the schematic arrangement in time and place under which the timber in a stand is harvested as compared to that of the other stands in the forest.

Evidently there can be a wide range as to size and shape of individual stands. The intensity of management has a great deal to do with determining both points. Size of stand tends to decrease as management becomes more intense. Topography, climatic factors, characteristics of the species in the forest, method of treatment, condition of the forest, and ownership are among the points which assist in determining the shape of individual stands. Strips, groups, areas of irregular outline, wide rectangles, and squares all find application and affect the general structure of the forest as a whole.

The schematic arrangement of these stands with respect to one another as to their geographic location and as to the time at which the timber is harvested is an important part of the forest structure. For example, a forest in which the stands and cuttings are arranged as shown in Figure 3 will have quite different structure from a forest in which the stands cut in successive years are arranged in a progressive series.

Another point not yet considered is that a forest, efficiently organized for the highest production possible on a given site, must contain an adequate amount of standing wood and timber retained as a forest capital (growing stock or principal) upon which adequate growth of valuable products may be laid. Cuttings control the amount of this forest capital and its distribution over the areas in the various stands comprising the forest. Cuttings also affect the microclimate of the forest and consequently influence all its life processes. Improper cuttings may result in injuries to the forest or even endanger its existence.

It cannot be too strongly emphasized that cutting operations leave their impress upon the forest and are the principal means available, when scientifically employed, to build up a forest into a technically sound and continuously productive enterprise. Silviculture indeed finds its highest expression through the gradual development of a forest, skillfully arranged as to ages and species, designed to take full advantage of the soil, and at the same time protected from injurious influences. All these matters fall within the field of silviculture.

At this point it will be of interest to inquire into the relationship between the field of silviculture and that of forest management. Silviculture deals with the technique of producing forest crops. Forest management covers the business aspects, including forest finance, policy, and general plan of work. Silviculture puts this plan into effect, so far as it concerns cutting and treatment of the forest, and in fact is responsible for a plan of development for building up the forest. It is the duty of management to test silvicultural accomplishment continually, particularly by applying the techniques of forest finance to determine costs and returns from silvicultural operations, both those proposed and those carried out. In practice it is difficult and not particularly important to separate the two fields and to know where one stops and the other begins. Applied silviculture cannot be just theory set aside separately from the business aspects of crop production. The two should be inseparable. Good silviculture never loses sight of the financial or business aspects of its operations. The term silvicultural management is often used to include both the technique of crop production and the business aspects directly related to production technique.

The field of silviculture divides logically into three parts defined as:

1. Treatment of the stand during the period of regeneration or establishment; a consideration of reproduction methods.

When a bare area is restocked with trees, either brought in by artificial means or originating from natural reproduction, there ensues a term of several years during which the soil is being prepared for reproduction and the young plants are being established or are adjusting themselves to the new environment. When this adjustment is successful and the reproduction is completed the period of establishment or regeneration may be considered closed.

In every stand the time comes, sooner or later, when it is desired to harvest a portion or all of the timber and to replace the trees removed by others of a new generation. Cuttings are made with the two purposes of removing the old trees and establishing reproduction. They are known as reproduction cuttings, and the period over which they extend is known as the regeneration or reproduction period. Reproduction cuttings range from one to several in number, and the regeneration period may extend from less than 5 to more than 50 years. In the selection forest this period is identical with the rotation.

2. Treatment of the stand during that portion of the rotation not included in the period of regeneration: a consideration of intermediate cuttings.

After a new stand is established on open land or on wooded areas as a result of reproduction cuttings, a long period ensues during which the young stand grows and passes through various stages until it is mature and ready, in its turn, to be harvested and to give place to a succeeding generation. The various cuttings made during its development from the reproduction stage to maturity are termed intermediate cuttings. They have as their object the improvement of the existing stand without thought of reproduction. (See Fig. 1.)

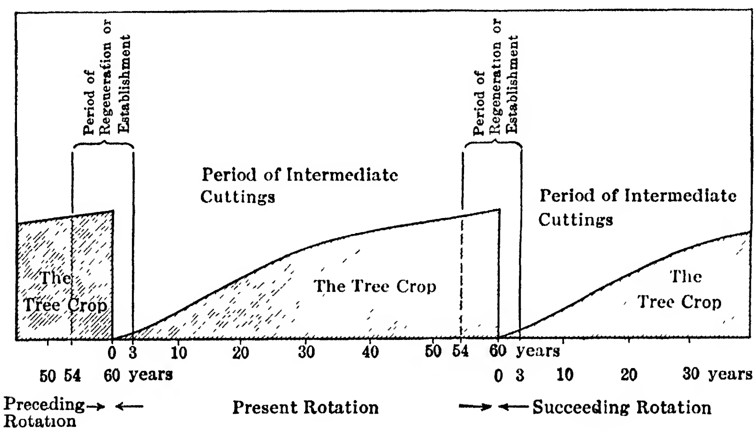

Fig. 1.

An illustration based on eastern white pine, managed on a 60-year rotation under shelterwood to show the relation between the period of regeneration and the period of intermediate cuttings.

3. Protection of the stand against injuries of many kinds. The more important are fire, insects, fungi, animals, and atmospheric agencies. This subject leads into various specialized fields, such as fire protection, forest entomology, pathology, and zoology.

Tree crops cannot be successfully grown without adequate protection. Such protection should be as much a part of applied silviculture as harvesting, regenerating, and tending the crop. Protection is in reality just one phase of crop tending but one which must constantly be kept in mind. In fact, oftentimes the details of successful silvicultural practice for a given species are determined by the protection factor. Although forest protection should be considered a branch of silviculture it can best be studied as a separate subject* and hence will not be fully treated in this book.

* Refer to *Forest Protection.* Ralph C. Hawley. John Wiley & Sons, New York, 1937.

The Cost of Silviculture and Relation to Utilization. In theory, consideration of costs, being a business or economic subject, belongs in the field of forest management (finance) rather than that of silviculture. However, in the practice of silviculture it is virtually impossible properly to appraise and choose between technical procedures of crop production independently of their financial aspect. The competent silviculturist never loses sight of the financial factor in his management of wood crops. There is, however, a tendency sometimes discernible to consider silviculture an impractical art. This opinion probably is based on the fact that as yet relatively little of the forest area in the United States is managed for the production of wood crops in contrast to exploitation of crops produced by nature.

Destruction or serious impairment of the productive power of the forest by previous mismanagement is the reason for lack of more widespread forest-crop production, not the impracticability of silviculture. To admit the latter is to admit that forest management for wood products is impracticable, since silviculture is the art which handles production under the general plan set up by forest management. Admittedly the economic conditions at any given time and place and for any owner will be the controlling factor in determining in each individual case whether production of wood crops, and particularly what method of such production, will pay.

In the great majority of forests today economic conditions justify the practice of silviculture under some method of technical procedure. It is true that over a large proportion of the forest lands only a crude or extensive application of silviculture may be justified. The crudest type of forest-crop production involves simply owning land and cutting off all the merchantable timber, after which nothing, except payment of the taxes and other carrying charges, is done until another merchantable crop develops and becomes available for cutting. Forest-land management of this type has been practiced in this country since the first title to land was obtained. It is far from being a good technique for forest-crop production although under certain ecological conditions it works reasonably well.

Economic conditions control the practice of silviculture as in a similar way they do the practice of agriculture on farm lands. Intensive silviculture, which calls for high expenditures per acre for cultural work and anticipates correspondingly high returns, like intensive agriculture pays only on the best lands and where markets for products are accessible and prices high. Elsewhere extensive silviculture requiring small expenditures per acre and returning a small income may be the most profitable type of management. Some

few areas on sites of low quality may prove unprofitable even under an extensive application of silviculture.

Silviculture, like agriculture and other commercial enterprises, requires expenditure or investment in order to secure some crop or return of more value than would be obtained without such action. The return in agriculture comes within one year or at most within a few years after the expenditure is made, whereas in the practice of silviculture, if started in a previously exploited and mismanaged forest, as it usually is, returns are delayed several decades. In either case the intensity of the work and the amount of the expenditure justified are in proportion to the return to be realized.

The long interval before the crop can be harvested is an undoubted drawback, but, in spite of this, expenditures in silvicultural and agricultural practice to increase productivity have a common economic basis. Indeed, when once adequately organized, forest properties producing timber crops may pay as well as or better than lands producing agricultural crops. However, the long interval of waiting, frequently necessary, for returns on expenditures made in the practice of silviculture explains why the idea is so commonly held that the application of silviculture is impractical. It requires for success good judgment to select the technique which will be profitable under prevailing economic conditions and ability to invest for future returns.

Most of the items of investment and expenditure pertaining to forest-land ownership must be incurred whether or not new wood crops are grown, and hence cannot be thought of as special silvicultural costs. Expenditures for technical supervision, marking of timber, protection of young crops, and a variety of silvicultural operations are distinctly costs of silviculture.

Compared with the cost of harvesting standing forest products, i.e., logging, the costs of silviculture often have been considered great, since logging simply conducts the first stages of utilization or manufacture of an existing crop of trees and does not have as an additional function the growing of succeeding crops. This type of comparison is quite often made because so many forest-land owners, now engaged primarily in logging merchantable timber, are considering the question of growing forest crops. Their first thought is to find what additional costs will be involved.

Experience shows that the practice of silviculture usually can be effected at a small additional cost or may, through reductions in the cost of logging, even result in a saving. Since the logging of large tracts often extends over several decades, it may prove cheaper to combine the two businesses of harvesting the existing crop and of

growing additional crops. In the past most owners of forest land were interested in harvesting the existing crop as a business in itself and gave no thought to producing another crop.

It is now recognized that in the case of many timber tracts, particularly where land ownership is of a permanent nature, the best financial results over a period of years come not from destructive exploitation of the existing stand but rather from harvesting this crop in such a way that production of future crops is assured. In the long run, the practice of silviculture, because it makes the forest a continuing resource, instead of being a source of expense will effect savings and reduce the costs of land management.

The practice of silviculture for the production of wood crops is pointless unless these crops are harvested and utilized. The crops are grown to be utilized, and their utilization is an essential part of the business of forestry. In fact profitable utilization is necessary for the successful practice of silviculture and is one of the essential factors in determining the details of silvicultural practice. Any attempt to divorce the practice of silviculture from the practical problems of utilization will prove disastrous.

Although harvesting the forest crop (logging) has in the past been a business in itself and will so continue for some time and indefinitely under certain conditions, in the long run its existence as an important industry is contingent upon the practice of silviculture. Somebody will have to grow the wood crops. It may be done by organizations now interested primarily in harvesting the crop, or by public agencies interested primarily in production and community development, or by various other types of forest-land owners.

The important point is that, if wood crops are to be provided in the future, silviculture must be put into practice generally on the forest areas.

In this present transitional period, when it has begun to dawn upon the logger that even for his business a combination of utilization plus production may be more profitable than destructive utilization alone, the costs of silviculture are receiving close scrutiny. A common way of expressing the costs of silviculture is to compare them with the cost of the business of logging, thus indicating the extra expenditures and investments, if any, required. This is of value, particularly, to demonstrate whether at the moment the change to a basis of permanent production can be afforded.

The question whether silviculture is profitable does not depend primarily upon the relative costs of the two distinct businesses — logging timber and growing timber — but upon whether a profit ul-

timately can be made in excess of the expenditures necessary in growing the tree crop.

It is true that the lack of capital to invest and of the financial strength to carry an investment for a period of years bars many owners of forest property from practicing silviculture. Where the desire to enter the business of forestry exists in conjunction with the requisite amount of capital, silviculture should prove a practical undertaking. Forest properties sufficiently well stocked with timber to return an immediate and continuous income offer more favorable opportunities for the practice of silviculture than those upon which the timber is so deficient as to necessitate a long period of waiting before returns on the investment are available.

One method of estimating the practicability of silviculture consists in figuring the costs of establishing and growing to maturity a crop of timber under prescribed methods of treatment and comparing these costs with the estimated returns. Such a calculation, involving as it does an estimate of future quantities and prices, is not entirely satisfactory but where conservatively made may prove of value. The estimate made some years ago by Cline and Lockard (1925) for mixed stands of eastern white pine and hardwood in Massachusetts illustrates the method. Their figures indicated an annual loss of 6 cents per acre in the first rotation (60 years) and subsequently a net profit of $6.29 per acre per year.

The costs and returns from planting and growing white pine and Norway spruce in Connecticut have been estimated by Hawley and Lutz (1943). Expenditures were estimated to amount to $118.37 per acre while the receipts from sale of stumpage were estimated at $516 per acre.

These two totals compounded at 3 per cent to the end of a 60-year rotation would accumulate to $408.91 per acre of expenditures and $573.27 per acre of receipts. This results in a surplus of $164.36 of receipts over expenditures during the rotation in addition to 3 per cent compound interest on the money invested.

The actual costs of silviculture and the degree to which they increase the cost of logging are subject to wide variation. In 1926 Show, speaking of the California pine region, placed the net increase in cost of applying the method of silviculture and protection approved by the United States Forest Service at not over 50 cents per thousand feet cut. Munger (1927) estimated the increased cost for measures necessary to secure continuous forest production in the Douglas-fir region to be 1 cent per acre annually for each acre of forest land plus 22 cents for each thousand feet of logs cut.

Bond (1939) estimated the costs and returns to be expected for the 30 years following the application of silviculture on a representative large tract of 100,000 acres of second-growth loblolly and shortleaf pine previously unmanaged. His figures indicate that a profit can be secured even in the beginning with increasingly better results as time passes. The data in Table I are taken from Bond's calculations:

TABLE I

	10 - *Year Period*		
Loblolly and Shortleaf Pine Forest	1*st*	2*nd*	3*rd*
Total gross returns* per acre per year	$1 046	$1.202	$1 793
Total cost per acre per year	0 204	0 230	0 295
Net returns including stumpage, interest, and profit per acre per year	$0.842	$0.972	$1.498
Rate of interest earned on the investment of $16.61 per acre	5 1%	5 8%	9 0%

*These figures include only the amount cut and make no allowance for increase in the growing stock by reason of the uncut growth.

In favorable instances a crude application of silviculture may involve very slight increased charges, or even be more profitable than the commonly used logging practice. On the other hand, intensive application may require large initial costs, although eventually returning better net profits than the crude application.

The various classes of items that must be considered in determining the cost of silviculture in an individual property may be grouped under the following five headings:

1. *Cost of reproduction.* The artificial regeneration of the area by seeding or planting may be required. Treatment of the soil, litter, ground cover, underbrush, or logging debris may be needed to establish proper seedbed conditions for natural reproduction. It may be necessary to retain a portion of the old stand, either for a part or for all of the next rotation, to provide seed or the right amount of shelter. The young seedlings, naturally or artificially started, may require assistance in the form of intermediate cuttings to secure their final establishment and thrifty development.

2. *Cost of protection.* Annual, periodic, or special expenditures against one or more enemies will be necessary. Examples are: the annual charges for the prevention of forest fires; the periodic eradication of *Ribes* species in white pine regions; and special work on cutting areas to dispose of logging debris, snags, and trees affected with fungi or insects or for fire suppression. The cost of insurance (where such can be economically secured), or the carrying and dis-

tribution of a certain fixed charge per acre to cover average losses from enemies, is a proper charge against silviculture.

3. *Increased expenses of logging, if any.* Increased costs of logging come principally through the need of greater care in felling, bucking, and skidding, to save young growth and seed trees left on the cutting area, and in the heightened costs per thousand feet, board measure, of construction work, due to a decreased cut when part of the merchantable stand is left. Leaving the smaller trees may effect a saving in logging costs, because such trees are the most expensive to handle and produce the lowest-quality product. Disposal of the slash may so clear the area as to effect a reduction in skidding costs.

4. *Cost of administration.* The marking of the trees to be cut or left and extra inspection and supervision to see that cutting and other work is carefully and properly executed are likely to be necessary.

5. *Costs, if any, from making the investment a permanent one.* The investment in the value of the land may become permanent instead of being terminated, through sale or devotion to other use, when the area is cut over. A considerable investment in wood capital (the growing stock) is required where silviculture is systematically applied.

Because of the favorable effect on annual depreciation charges, making the investment permanent through application of silviculture, as contrasted to liquidation, in most cases should not result in increasing costs but may effect a decrease.

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CHAPTER II

REPRODUCTION METHODS

Treatment of the Stand during the Period of Regeneration or Establishment

Definition. A reproduction method may be defined as an orderly procedure or process by which a forest is renewed or established either naturally or artificially. This process is accomplished during the reproduction or regeneration period, which comes when the stand is harvested at the end of every rotation. It is accomplished through skillful cuttings of the mature timber supplemented where necessary by special treatment to create and maintain conditions favorable for the start and early life of reproduction. The reproduction method includes both the removal of the old stand and the establishment of a new crop. Where artificial methods of regeneration are employed, as in reforesting open lands and sometimes in renewing established forests, the seeding or planting of the area is included as part of the process.

The term "silvicultural system" sometimes is used as practically synonymous with reproduction method. Strictly speaking, the former term is more comprehensive and covers the whole plan for silvicultural treatment during the life of the stand, including both reproduction and intermediate cuttings. Silvicultural system as defined by Troup (**1928**) is "the process by which the crops constituting the forest are tended, removed and replaced by new crops resulting in the production of woods of a distinctive form." Under the term "tending" as used in this definition is included treatment of immature stands so far as it affects the condition of the soil and crop at the beginning of the regeneration period. Troup's definition of silvicultural system emphasizes the decisive influence that the cutting operations have upon the form of the forest.

Classification of Reproduction Methods. Many different reproduction methods have been developed, but they can be reduced on analysis to a few standard methods applicable in principle the world round. In practice the details of applying the same reproduction method may vary for every species, forest region, and owner. As time passes this leads to the origin of quite definite reproduction

methods worked out in detail and based on local practice which may be advanced as original and advocated for general adoption. Under close examination such methods prove to be mere modifications of the few standard reproduction methods and less applicable than the latter for general use.

The list that follows, arranged to meet American conditions, contains only six methods. Each of these methods is treated in a separate chapter and may be further subdivided. Reference should be made to the individual chapters for definitions and discussion of the methods. It should be realized that no one reproduction method is always preferable. Each of the methods discussed has something to recommend it and may under certain circumstances be the best one to employ.

High-forest methods: Producing forests originating from seed.

Clearcutting method.
Seed-tree method.
Shelterwood method.
Selection method.

Coppice-forest methods: Producing forests originating wholly or mainly from sprouts and suckers.

Coppice method.
Coppice with standards method.

The Basis of Distinction between Reproduction Methods. In the reproduction method two activities are involved: the removal of the old timber, and its replacement with a crop of young trees. A wide range of possibilities is available in removing the old timber, varying all the way from its gradual removal over a long period of years by scattered single trees to sudden and complete removal of the trees on large areas. The removal of the old timber is entirely within the control of man. This is not so true of the establishment of the new crop. Nature here plays an important part and often thwarts or modifies man's efforts. This is the case even where young trees are artificially established on the area, since their survival is not necessarily secured by the act of planting.

Natural regeneration starts either under shelter, when the seed falls beneath the seed-bearing trees and other older trees on the area, or on open areas, when the seed comes either from trees standing on the side of the bare areas or from trees taken out in the cutting. Here also as with the removal of the old timber a wide range of possibilities is available, from large areas completely exposed where

seed must be transported considerable distances from the side and must germinate and survive on open areas, to practically complete cover where the seed drops from overhead, germinates, and starts development under heavy shade. In the forest both forms of seeding are likely to operate together in the same stand and often cannot be separated. Reproduction under shelter is characteristic of the selection and shelterwood methods; reproduction on open areas is the chief mainstay of the clearcutting method.

The detailed procedures in removing the old timber and in establishing the new crop are the basis of distinction between reproduction methods. In particular, the method of cutting — which may be either clearcutting or partial cutting of the shelterwood or of the selection type — and the size, form, and position of the areas cut over are of importance in this connection. They determine the age-class arrangement, which in turn is the factor governing forest form. Each reproduction method, when systematically applied in a forest during the lifetime of a forest crop, produces a characteristic forest structure by which it can be recognized.

In reducing the number of high-forest methods from the dozen or more found in European practice to the four listed for American practice the principle has been to divide the range covering all possible ways of removing the old timber and establishing the new crop into a few reproduction methods radically different from one another and together representing the entire range of possibilities. Thus the classification of reproduction methods should be recognized and ap-ied as a framework allowing wide range in respect to details to fit e local conditions in each forest. Natural reproduction follows ttings not as a direct result of the cuttings themselves, but owing favorable site conditions and to a supply of seed. Theoretically, vorable site conditions should be created or improved by the ttings. A reproduction method is successful in so far as it ac-mplishes this, and the variation in detail of application has as one rpose the creation and maintenance of conditions favorable for generation.

As reproduction methods are studied it becomes apparent that e method grades into another and that into still another and so in a complete series embracing all the possible ways of removing a ature stand by cutting. In passing through this series there can obtained every conceivable combination of open and dense stands, oung and old trees, of protection or exposure, with the consequent num range in desired effect upon basic site factors possible to e by cuttings.

Just as the sites in a given region range in a continuous series from the least to the most productive but are separated arbitrarily into a few broad classes for use, so with reproduction methods the gradations from one method through various modifications to another method are almost unnoticed when taken step by step, yet show extremes at the limits of the series and are for purposes of practical use classed into a few main divisions. Any possible combination of cuttings for harvesting a merchantable crop of timber and replacing it by a new stand can be placed under one of the six reproduction methods listed.

At the present time in North America most of the harvesting of timber is being done in the irregular overmature virgin forest or in forests previously culled without provision for a new crop. Frequently the style of cutting has been rather rigidly circumscribed by the condition of the timber, logging possibilities, and other economic conditions and has consisted in removing all or a very large proportion of the merchantable timber without thought of any particular reproduction method. Nevertheless these cuttings when examined and when the policy with respect to further operations is known can be identified and classified under the appropriate method.

These forests are in the transition stage between the unmanaged forest of the past and the managed forest of the future. Such reproduction as follows the cutting comes haphazard and uncontrolled but will receive protection. After the first cutting which utilizes principally overmature trees the possibilities and necessity of cutting more systematically to secure reproduction will be seen. At the same time many mistakes could be avoided if the forester, at the time of marking for the first cutting (even in an irregular overmature virgin forest), would give some thought to the reproduction method which will be the best to apply in the long run and govern his marking accordingly.

Combinations of several reproduction methods within the same stand are common practice in treating the irregular unmanaged forests which are the rule today. Even in stands long under treatment more than one reproduction method may be used to meet varying conditions satisfactorily. Eventually only one standard method is likely to be applied within a single stand because each method produces distinctive results and recognizable differences in the structure of the forest, which usually make it advisable to have stand boundaries coincide with variations in reproduction methods. For a clear understanding of reproduction methods it is advisable to keep in mind the distinction between "forest" and "stand." A stand is a

portion of a forest, contains only one forest type and age classification, and is the smallest silvicultural unit or subdivision of the forest recognized in practice. A large forest is likely to contain hundreds of stands.

As previously stated, each reproduction method stamps its imprint upon the forest. This is expressed outwardly by the forest form. Certain reproduction methods result, for example, in the maintenance of evenaged stands; others produce stands either unevenaged or of varying degrees of irregularity. Regularity or irregularity of age in the managed stand depends upon the length of the reproduction period. During this period in the life of a stand reproduction may be continuously in process of establishment and the trees of the new crop may vary in age by as many years as the reproduction period is long. Where the reproduction is starting throughout the life of the stand a true unevenaged stand is likely to result. Where the reproduction period is reduced to one year, as it may occasionally be in the coppice method or where a clearcut area is planted, the stand is absolutely evenaged. Most evenaged stands, however, contain trees of more than one age because the reproduction period rarely can be restricted to a single year. In practice a stand may be considered evenaged provided that the difference in age between the oldest and the youngest trees does not exceed 20 per cent of the rotation age.

The length of the reproduction period in reference to the length of the rotation determines the allowable range in age between indi- al trees if a particular stand is to be classed as evenaged. The er the rotation the greater can be the difference in age between in- lual trees without loss of the evenaged form. For instance if the ion is 50 years, a difference in age of 10 years might be the imum if the stand is to remain evenaged, whereas if the rotation 200 years, differences of 40 to 50 years between individuals d be allowable.

he evenaged and unevenaged forms of stand structure each result e production of timber having somewhat different characteristics, h should be kept in mind at the time reproduction methods are receiving consideration.

Trees grown in evenaged arrangement are, relatively speaking, characterized by:

Cylindrical stem form and straight stems.
Small size of branches and narrow crown.
Long bole free of branches.
Satisfactory, but not high, live-crown ratio.
Susceptibility to injury from storms, fire, insects, and fungi.

Even height of adjoining trees, tending toward regularity in size and quality, and intimate competition between individuals of the same age.

In contrast trees grown in unevenaged arrangement are, relatively speaking, characterized by:

Tapering stem form.
Large size of branches and wide crown.
Short length free of branches.
High live-crown ratio.
Resistance to injury from storms, fire, insects, and fungi.
Irregularity in height of adjoining trees, tending toward a great variation in size and quality, and competition which suppresses young trees and leaves large trees in open position.

On the whole the evenaged arrangement is considered more advantageous than the unevenaged. Susceptibility to injury can to large extent be overcome by reducing the size of the area occupied by an evenaged stand. The advantages of evenaged form are retained, even if groups less than an acre in size constitute the evenaged unit.

Origin of the reproduction, whether from sprout or seed, whether naturally or artificially obtained, is also used as a basis for distinction between reproduction methods. Origin serves particularly to separate coppice methods that rely on sprout regeneration from the high-forest methods employing regeneration from seed.

Factors Which Affect the Establishment of Natural Reproduction. The method of cutting is only one among a number of factors which control the establishment of natural reproduction; others are climatic conditions (often the dominating factor), supply of seed, occurrence of fire, and influence of animals, insects, and fungi. All these factors, outside of what direct mechanical influence some of them may exert in destroying established reproduction, affect the start and early development of reproduction through influence upon such fundamental factors as temperature, moisture, and light, which are of direct controlling importance. For successful natural reproduction there must be:

1. Abundant seed supply in excess of that destroyed by rodents, insects, and other agencies.
2. Favorable conditions for germination of seed.
3. Favorable conditions for the growth of seedlings.

Each species is likely to have different requirements and will vary more or less in its own requirements in different parts of its range. Some one factor or combination of several factors may be

of critical importance in obtaining reproduction. A few illustrations may serve to emphasize this point. For example, shortage of seed and attacks by rodents and cutworms are reported to be the most serious factors in preventing ponderosa pine reproduction in California (Fowells 1940). Hogs, by uprooting longleaf pine seedlings, are so likely to destroy areas of reproduction completely that they must be fenced out until the seedlings are too big to be destroyed. However, even when hogs are excluded and other factors are favorable, it has been found in southern Mississippi that birds may prevent reproduction by feeding on the longleaf pine seeds (Burleigh 1938). Pearson (1942) has studied the effect of herbaceous vegetation (particularly grasses) on natural regeneration of ponderosa pine in the Southwest and finds that it may be an important factor in the establishment of natural regeneration both by root competition for moisture and to lesser extent by reduction of the light reaching small seedlings.

The silviculturist should be equipped with a definite knowledge of the basic requirements for natural reproduction of the species with which he deals and should also know the effect of cutting methods, fire, grazing, wildlife, and other factors upon establishing and maintaining these requirements. Supplied with this knowledge he can utilize cuttings, fire, and other means, so far as control of them may be in his power, to establish and maintain the conditions requisite for reproduction.

As previously stated, a reproduction method has for its object the establishment of reproduction and the removal of the old crop. Reproduction may possibly, though rarely, be established as a direct result of the cuttings. More probably the method of cutting is only one of a number of factors, some within the control, some beyond the control, of the silviculturist, but each exerting its effect on environmental conditions. The method of removing the old crop should always be one which will create favorable environmental conditions for the particular species it is desired to reproduce.

As a general principle, cutting, since by opening the forest it increases the light and heat reaching the soil, has a tendency to favor reproduction of species characteristic of a successional stage farther from the climax than that existing before the cutting. A complex of other factors may modify this influence, but successional trends should always be kept in mind, together with the fact that it may or may not be desirable to advance toward a climax forest.

A reproduction method includes more than the making of cuttings. Other work to insure reproduction may have to be pursued. For

example, the use of fire, protective measures against insects and animals, cultural operations to prepare the soil, to conserve moisture, and to lessen the competition with grass, herbs, and shrubs, the use or exclusion of grazing, and disposal of slash are procedures that may have a vital connection with the securing of a complete reproduction.

Species Composition and Arrangement of the Species in the Stand. In theory the reproduction method to large extent controls both the species composition and the arrangement of species in the new stand. In actual practice the degree to which this control can be exercised is governed by the reproduction method employed, by the complex of factors affecting the establishment of reproduction, and by the degree of intensity with which in a given place silviculture is applied. For example, it is much easier to obtain in the new stand exactly the species and arrangement wanted, and no others, when clearcutting with artificial reproduction is employed and intensive cultural operations are financially practicable than when a crude application of the selection method with natural regeneration unassisted by cultural operations is employed.

The silviculturist should have definitely in mind the composition desired in the new crop and the arrangement of the species, whether by single trees, small or large groups, or in pure stands. This concept as set up should of course be reasonably attainable under the given biotic and economic conditions. Even then, it is often difficult to so control the complex of factors influencing reproduction as to obtain in practice just the composition and arrangement of species desired. What the composition and arrangement of species should be must be decided locally for each part of a forest on the basis of the site factors and the economic factor.

Evenaged stands are easier to manage than unevenaged stands, which, however, may be safer against some types of injury such as wind.

Voluminous discussion has arisen over whether composition of stands should be pure, i.e., made up essentially of only one species, or whether such arrangement should be avoided in favor of a mixture of two or more species, either by single trees or groups of various sizes. Without going into a full discussion of the subject at this point it may be said that no general answer will hold true everywhere. The fact to emphasize is that both pure and mixed stands occur in nature and may be employed safely in the practice of silviculture under appropriate conditions. It is well to remember that a species gregarious by nature can in all probability be grown safely in

pure stands, but a species that in nature occurs only as scattered individuals in mixed stands is likely when growing alone to prove susceptible to insect attack or to disease.

Silviculturally the mixed stand has been considered superior to the pure stand in maintaining the fertility of the soil, in rate of production (caused both by greater fertility of the soil and by occupying the site more completely), and in lower susceptibility to injurious agencies. In most instances this may prove to be more of theoretical than of practical importance. Fertility of the soil on an absolute basis is undoubtedly affected by the litter falling from the trees in a forest stand. Each species has its own characteristic litter which may with one species be strongly acid, while with another it may contain relatively large amounts of calcium. Under a stand of the latter species the absolute fertility of the soil as measured by soil scientists is likely to be better than under a stand of the former species. Undoubtedly both mixtures and pure stands can be formed of species whose litter will have a tendency to improve the absolute fertility of the soil. It is equally true that both mixtures and pure stands can be formed of species whose litter will have a tendency to lower the absolute fertility of the soil.

Heiberg (1939) has indicated that both pure and mixed stands may be found that are capable of maintaining soil fertility, and that their capacity to do so depends upon the ability of species to assist in maintaining good physical conditions in the soil even more than upon the exact amount of chemicals in their litter. For example deep-rooted species would have a better influence than surface-rooted species. The point to emphasize is that the inherent characteristics of the species, not the question of pure versus mixed stands, determine the effect of that forest upon soil fertility.

Climate and topographic situation also affect levels of soil fertility. A cold climate and a shallow, dry soil may be expected to have an adverse effect upon productivity. As species often have a climatic and topographic zonation, effects of these factors on soil fertility are often wrongly assigned to species. The fact is there is a different degree of soil fertility characteristic of stands of each species, climate and site. Since the objective of silviculture is not maintenance of the highest absolute degree of soil fertility, it is not necessary to select combinations of species which show highest soil-fertility values on an absolute basis.

Reliable experimental evidence that the rate of production is less in pure than in mixed stands appear to be non-existent. In fact Burger (1928) investigated this subject and came to the conclusion

that pure and mixed stands had approximately the same volume increment.

In principle mixed stands are more secure than pure stands against damage from such causes as fire, insects, disease, and wind, but in practice this point is usually not a critical factor. Pure stands are rendered more secure if they are kept small in area and with variation in age between adjoining stands. Mixtures can be only as secure as the species in the stand. If these species are inherently resistant to injurious influences the stand may be safe. Chestnut was destroyed by the chestnut blight with equal thoroughness both where it occurred in pure stands and where it was found as a scattered tree in mixture. Other cases can be found where mixture with one or more species has prevented or lessened injury to a given species as contrasted to results in pure stands. A great deal depends upon the relative susceptibility of a species to injurious agencies. In the long run exceedingly susceptible species are likely to be eliminated both in pure and in mixed stands. Champion (1933) attempted while traveling in Europe to find specific instances of losses which could be directly attributed to pure composition of the stand, but he reports negative results.

The best mixtures are those composed of one or more shade-enduring species grown with one or more light-demanding species, the latter having a faster rate of height growth than the former. Mixtures as well as pure stands may be developed either artificially by seeding and planting or naturally.

In talking about pure versus mixed stands, as well as about even-aged versus unevenaged stands, usually the great extremes are compared, but in actual practice the forest is to very large extent well between these extremes.

Artificial Reproduction Compared with Natural Reproduction. Establishment or renewal of a forest may be obtained by (*a*) seed, (*b*) sprouts from the stump or from the roots (root suckers), (*c*) cuttings, and (*d*) layering. In the practice of silviculture, layering is not employed, cuttings are used infrequently, and dependence is placed mainly upon seed or sprouts to ensure reproduction.

Reproduction may be accomplished by either natural or artificial means. Natural reproduction accomplishes its purpose by self-sown seeds or by sprouts and, in instances so rare as to have no commercial importance, by layering. Artificial reproduction, defined as the renewal of a forest by direct seeding or planting, utilizes either seeds or young plants grown from seeds or cuttings.

Of the two methods natural reproduction is of outstanding im-

portance, being used at present on all but a small proportion of the forest area. Artificial reproduction may be employed in connection with any of the reproduction methods under special circumstances and to supplement natural reproduction.

Artificial reproduction is frequently treated as a unit by itself in special publications. This is due to the fact that two subjects, namely, the collection and treatment of tree seeds and the growing in nurseries of trees for planting, must be developed intensively in connection with the establishment of forests by artificial means. A condensed statement covering the subjects of seed collection, nursery practice, and establishment of forests by seeding and planting is included in Chapter III in connection with the reproduction method of clearcutting with artificial reproduction. It is in connection either with this method of regenerating forests or with reforesting bare lands that artificial reproduction finds its most common application. A comparison of natural and artificial reproduction is presented in the succeeding pages.

In theory the removal of the old timber should be followed immediately by establishment of the new crop. In practice often a number of years is lost before reproduction is complete. In the managed forest time is an important factor. The long delays often experienced in obtaining natural regeneration must be avoided. One advantage claimed for artificial reproduction is that this loss of time is avoided because sturdy trees for the new crop can be planted immediately after the harvesting of the timber. Time will be gained both because the trees may be several years old when set out and because the ground does not lie idle for one or more years as may happen if reliance is placed upon natural regeneration. In difficult cases it may take from 10 to 30 years after the cutting for an area to restock completely by natural means, owing either to lack of seed years or to other unfavorable conditions. On bare areas natural reproduction usually cannot be secured after a cutting without some delay. On the other hand under certain reproduction methods, such as shelterwood, natural reproduction can be secured before the old timber is harvested, thus avoiding any loss of time. Artificial reproduction cannot always follow immediately after the harvest of the old timber. For example, in applying the clearcutting method with planting to stands of eastern white pine, the planting of the new crop must be delayed until the second or third year after cutting to avoid destruction of the reproduction by an insect known as the pales weevil (*Hylobius pales*). On short rotations and where intensive application of silviculture is justified saving one or more

years of time may be of distinct financial benefit. Where only extensive application is appropriate the saving of a few years' time in securing reproduction is not important.

Control as to the species which will compose the new crop is desirable but often is difficult of attainment by natural reproduction. Artificial reproduction makes it possible to obtain exactly the one or more species capable of thriving on the site in question and best adapted to fulfilling the objectives of management. Frequently the trees which reproduce naturally on a given area are inferior in value and rate of growth to other varieties that could be grown. This is by no means always true, for excellent natural reproduction of species desired often can be obtained. Where a species that is not present in the original stand or in adjoining stands within seeding distance is wanted, artificial reproduction must be employed. In many instances natural reproduction may appear in large enough quantities to stock the area but may prove to be of the wrong species. Natural reproduction in mixed stands is especially difficult to predict because of this factor.

The correct density of stocking, at each age, necessary to produce the best quality of the product desired is one objective in the practice of silviculture. Natural reproduction is apt to give either too sparse or too dense stocking, particularly the latter. Frequently expensive treatment to correct overstocking is necessary at an early age. Artificial reproduction, on the other hand, permits the correct number of trees per acre to be established and complete reproduction is more certain. In theory this is true, but in practice it is sometimes too expensive to obtain artificially as dense a stand as would be silviculturally desirable during the early part of the rotation. The advantage of a thick, even, stand of seedlings whether naturally or artificially obtained is that this condition usually results in intensified selection among the plants, those inherently the best surviving in the ensuing severe competition.

The yield per acre in quantity and value should average higher in artificially than in naturally reproduced stands owing principally to the saving in time of establishment, the use of the best species, and the right spacing of the trees. Although this is in general true many exceptions to the rule occur. There undoubtedly are many naturally reproduced stands that yield as much as, or more than, those artificially reproduced.

It is sometimes alleged that the safety and vigor of the stand may be affected unfavorably by the use of artificial reproduction. Proponents of this argument make much of the fact that natural

reproduction, as its name implies, is nature's method, free of man's interference, and consequently, they claim, should renew the forest with healthy trees adapted to the site. This may be countered by showing that artificial reproduction, correctly applied, makes use only of species and healthy plants of local strain and adapted to the site. It may even be that by using seed from better trees than those now in the stand the race in a given locality may be improved.

If the new crop established by natural rather than artificial means is safer and more vigorous, then it must be from causes functioning after the new crop is established. What are the possibilities of such an occurrence? It is sometimes inferred that natural regeneration necessarily produces a mixed forest whereas artificial regeneration necessarily results in a pure one. This is a faulty generalization, derived perhaps from consideration of virgin forests undisturbed by other than natural factors, and not equally true for forests after cuttings. In fact not all virgin forests are mixed, as a study of ponderosa pine forests will prove. On the one hand there can be seen in this country wonderfully fine pure stands, naturally reproduced, of the following pines: longleaf, loblolly, slash, shortleaf, eastern white, western white, jack, red, ponderosa, and lodgepole; and also of Douglas-fir, balsam, red and black spruces, yellowpoplar, aspens, paper birch, sweetgum, and sugar maple. On the other hand, while most of the stands artificially established in this country in the past have been of a single species (pure), examples of mixed stands can be found and there is no fundamental difficulty in artificially establishing mixed stands if they are desired.

The relatively wide spacing of the individual trees customarily used in artificial reproduction, while providing a complete stocking of the area, induces fast growth in the young plants for the first few years until the adjoining individuals begin to crowd one another. After the stand closes competition becomes intense and brings a marked reduction in both live crown and roots. In this period root rot is more likely than at other times to gain entrance to the roots and may result ultimately in serious injury to the artificially regenerated stand. How serious a factor for different species in America this may prove to be is yet to be determined.

Artificial reproduction has been used in managing stands of Scotch pine and Norway spruce in Europe over long periods of time without bad results to the safety and vigor of the stands, except in occasional instances where factors other than the method of establishing regeneration were responsible.

Natural reproduction is cheaper on the whole, or at least requires

less direct cash outlay, than artificial reproduction. On many forest areas natural reproduction can be secured for practically nothing or at a fraction of the expenditure required to reforest artificially. The natural reproduction obtained so cheaply and the stand finally produced may or may not compare favorably in composition or density with those originating under artificial methods. However, in many forest types excellent natural reproduction is established cheaply. How the naturally reproduced stand will compare in final net value with the more costly artificially reproduced stand is a local problem to be determined for individual stands.

There are, however, many cases where natural regeneration does cost more than artificial reproduction. The trees left to establish reproduction reduce the cut per acre and hence increase the unit cost of logging the timber on the area. Furthermore these trees may perish, causing a loss of investment equivalent to their stumpage value. Expenditures for preparation of the seedbed may be required.

The relative costs of natural and artificial reproduction should be ascertained wherever cost is the primary factor in determining the choice between the two. Cost alone, without consideration of the completeness and potential quality of the new crop, is not the best criterion. A new crop which will be composed of the best species and will fully stock the whole area, in contrast to one partially stocked or composed of inferior species, may be worth paying more to obtain. Even when greater net returns of artificially reproduced stands can quite clearly be demonstrated, the actual amount of initial cash expenditure may make the proposition impracticable for the owner.

Artificial reproduction permits the employment of a relatively simple management plan and reproduction method, whereas more complicated and hence expensive methods requiring greater skill may be required to secure equally good reproduction naturally.

However, natural reproduction as compared with artificial reproduction is better suited to the less intensive methods of silviculture which must be employed for many years over the larger share of the forest area. To regenerate existing forests by artificial methods requires work of intensive character for which the country is not ready on a big scale. It should not be assumed that even when intensive silviculture becomes possible natural reproduction will be superseded by artificial reproduction. The tendency today, where conditions for intensive silviculture are best, is to prefer natural reproduction and to spend enough money to obtain establishment of satisfactory natural reproduction. Such expenditures often are

greater than can be justified under the less intensive methods of silviculture at present more widely applicable.

In many instances the establishment of natural regeneration is a difficult technical problem and requires silvicultural skill of high degree. This fact has not been thoroughly appreciated in this country because we have found in our old-growth forests, and been able to use for a new crop, so much advance reproduction built up without consideration of the time factor or special cultural operations. As managed second growth comes along in its development to the regeneration period, the need for skillful application of silviculture will receive fuller recognition.

Dengler (1935, p. 367) believes that it is harder to get good natural regeneration in the managed than in the virgin forest, because in the former the effort is to develop the most valuable timber trees and often the branchiest and best seed-bearing trees are removed. Furthermore, as long periods of waiting for reproduction as in the virgin forest cannot be afforded in the managed forest. For these reasons he thinks natural regeneration in Germany is not so good now as it was long ago.

It must be evident from the preceding paragraphs that there is no decisive answer to the question of natural reproduction versus artificial reproduction. In some places natural reproduction will be better; in others, artificial reproduction is preferable. Each should be made use of as conditions warrant for the specific area concerned. Excellent forests can be created by either method. In this connection the conclusions of Champion (1938, p. 173) are worth quoting:

"In general terms, it may be said that natural regeneration should be preferred to artificial wherever it can be accomplished with reasonable expedition, certainty and cost. If the operations are liable to be drawn out, to include a considerable proportion of failure, and to be costly, then artificial regeneration is to be preferred, and it is almost always sound policy to finish off natural regeneration by artificial work after giving the former a reasonable time to accomplish what it can."

Opportunities for Applying Artificial Reproduction. In general the field for artificial reproduction today is in reforesting burns and other areas which are at present non-forested and which either are so far distant from seed trees or suffer such unfavorable site conditions as to preclude the possibility of natural restocking in the near future. Old clearcuttings and burns amounting to millions of acres in the United States, together with other open lands, will require many decades to reforest and will tax the capacity of all

agencies to supply necessary seeds, plants, labor, and funds. Since these areas are at present relatively unproductive, artificial reproduction should be largely confined for the next half century to reforesting the better soils and more accessible portions of this type of land.

Only in regions and on sites where intensive management is profitable and in which the proportion of open unproductive land is small should artificial reproduction of existing forests be undertaken. Here the funds for relatively large initial outlay often are available, and the size of the projects is within the range of present physical limitations.

Artificial methods of reproduction are most commonly applied when using the clearcutting method or in reforesting open land. There is a field for artificial regeneration under other reproduction methods, intensively applied, to supplement natural reproduction by stocking the blanks and by introducing new species into the stand.

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CHAPTER III

THE CLEARCUTTING METHOD

Definition. In the clearcutting method the area is cut clear. This involves cutting the entire stand and results in removal of the forest on the area clearcut. The term " clearcutting " is sometimes erroneously applied to any type of cutting that removes all the merchantable timber but leaves smaller trees, cull individuals of merchantable size, and all individuals of unmerchantable species. Where only relatively large trees are merchantable and there occur numerous individuals of valuable species but unmerchantable size, as well as trees of merchantable size but unsalable species, the removal of only the merchantable trees may constitute a light partial cutting without any resemblance to clearcutting. Typical clearcutting lays bare the area so treated. This is the concept of the method and the purpose in its application as a method of silviculture.

Reproduction is secured after the cutting either artificially by seeding or planting or naturally by seed distributed from trees standing outside the area cleared or from trees felled in the cutting operation. Depending on how reproduction is secured the method divides into (*a*) clearcutting with artificial reproduction and (*b*) clearcutting with natural reproduction.

Form of Forest Produced. A clearcutting operation as an economic method can be used only in a stand where practically all the trees are merchantable. Such a stand may either be evenaged or contain several age classes, the youngest of which contains trees as large as or larger than the minimum merchantable size. The new stand originating on a clearcut area is evenaged, irrespective of whether the timber before the cutting was irregular or evenaged. In almost all stands of merchantable timber, no matter how evenaged in form, there will be occasional trees below merchantable size, cull trees, or individuals of unsalable species which remain standing after a clearcutting. Since complete removal of the old stand is wanted, these trees may be girdled or felled, although the majority of such trees if standing isolated may soon be windthrown or die as a result of the changed conditions following the cutting.

The two different ways of securing reproduction require separate consideration in discussing the details of the clearcutting method.

The remainder of this chapter is devoted to clearcutting with artificial reproduction; the succeeding chapter is given over to consideration of clearcutting with natural reproduction.

Clearcutting with Artificial Reproduction. In this simple method the stand is cut clear and reproduced by seeding or planting. Usually the artificial regeneration is accomplished soon after the clearcutting. The cleared area is likely to become stocked with grass, weeds, underbrush, or undesirable trees which may prevent or render expensive the process of artificial reproduction. In exceptional cases it may be of advantage to delay seeding or planting for one or more years, as when it is desired to allow time for a thick humus to decompose or when injuries to the new stand by insects breeding in stumps or tops can be avoided by delay. When stands of eastern white pine are clearcut in New England the pales weevil attracted by the fresh-cut trees becomes abundant on the area and will destroy new plants for two years after the clearcutting. Hence planting of this species should be postponed until the second or third season after cutting when the pales weevil has decreased in numbers.

Lumber, logs, and cordwood should be removed from the area before it is regenerated in order to prevent damage to the young plants.

A clearcutting results in a large accumulation of tree tops and other logging debris. This may be so abundant as to interfere mechanically with the seeding or planting operations or constitute a serious fire hazard. If so this material should be disposed of by one of the methods described in the chapter relating to slash disposal. Heavy underbrush may have to be treated in a similar manner.

As the young reproduction develops it will on many sites be overtopped by inferior trees and other vegetation. The proper treatment of the young stand under such circumstances is discussed in Chapter X under "Cleanings" and "Liberation Cuttings."

In artificially reproducing an area two preliminary questions require consideration, namely what species to use and whether the species should be arranged in pure or in mixed stands. Answers to these questions are here discussed briefly in general terms, since in application each area should be given individual consideration.

The species selected should first of all be suited to the climate and the site and then be those which promise the best net returns, considering a variety of factors such as the costs of establishment and management, susceptibility to injurious agencies, the rate of growth, and the usefulness and value of the products. Native species already thriving in the locality are the safest choice. Sometimes a tree not found locally merits consideration. In that case the relative value of

the product, as compared to that supplied by other species, and the cost of artificial reproduction may be determined in advance with reasonable accuracy. The extent to which a species not native to the locality is adapted to the site and will thrive there is difficult to determine without experimentation.

The introduction of an exotic species, particularly from a foreign country, should never be undertaken unless substantial evidence can be obtained indicating its adaptability to the local climate and site. Most of the failures, in those artificially reproduced stands which have received intelligent management after establishment, can be traced to choice of a species ill adapted to the climate or to the site. Since many species have a broad range within which decided variation in environmental factors occurs, it may not be sufficient simply to select a given species for artificial reproduction on a specific tract. Instead, it may be necessary to restrict selection to individual plants or seed taken from that specified portion of the total range which most closely approximates climate and site characteristic of the areas to be reproduced. (See page 38.)

The question of pure or mixed arrangement of the species is of particular importance in artificial reproduction since here it is possible definitely to control the composition of the stand. The comparative merits of these two arrangements were discussed on page 25. From the business standpoint it is cheaper, simpler, and requires less technical knowledge to establish and maintain a pure stand than one containing several species. As far as the actual work of setting out the young plants or sowing the seeds is concerned, starting a mixed stand costs very little more or no more than starting a pure one. The extra trouble of handling two or more species, and controlling their desired arrangement on the area to be reproduced, may even be more than compensated by the lesser cost of the planting stock or seeds for one of the species. On the other hand success in maintaining a mixed stand requires accurate information as to the comparative growth rate and the relative needs for light and growing space of the species when associated in mixture. This knowledge for most of our species has not yet been acquired.

Mixture by single trees of each species, though it gives an intimate mixture, is an unwise arrangement unless the species are particularly suited for such association. As yet our knowledge of the behavior of various species when so associated is not always adequate to make this type of arrangement practicable. The best arrangement is by small groups of a few trees of one species interspersed with similar groups of the other species. In this way each species will have

freedom to develop a small unit of its own kind, protected from encroachment and possibly complete suppression by adjoining species, something which often happens in single-tree mixtures. Mixtures composed of both light-demanding and shade-enduring species are the best. In such an arrangement the light-demanding species should be of faster growth and yield more valuable products than the associated shade-enduring species. Mixture by rows is less desirable than by small groups. Single rows of each species are subject to the same danger of elimination of one or more species which is characteristic of the single-tree arrangement. If rows are used at all each species should be established in a belt 3 or 4 rows wide.

On the whole the artificial establishment and management of mixed stands is a relatively untried field of silvicultural practice which merits more attention in the future but which in many instances should not be substituted for pure stands.

Artificial reproduction, whether used in connection with the clearcutting method or in creating forests on non-forested areas, requires preparations to provide the necessary plant material, either seeds or plants, for establishing the new forest. Artificial reproduction is divided into two methods of operation. In the first, known as direct seeding, the new crop is established by means of seed sown right on the ground where it germinates, and the trees grow permanently without transplanting. In the second, termed planting, the new crop is established by means of small plants which usually are specially grown in nurseries until one to several years old before being set out on their permanent locations. A large amount of technical detail is involved in providing the right kind of plant material and in getting this material successfully established on the areas to be artificially reproduced. The work may best be considered under four subdivisions as follows:

1. The seed supply.
2. Nursery operations.
3. Artificial reproduction by direct seeding.
4. Artificial reproduction by planting.

Each of these subjects is treated here briefly. For more detailed treatment special treatises on artificial reproduction should be consulted. See for example Baldwin (1942), Toumey and Korstian (1942), and Wakeley (1935).

The Seed Supply. Good seed is a prerequisite for success in artificial regeneration. This statement implies that the tree must, first, be of a species climatically suited to the region and the soil and, second, have no undesirable inherent characteristics.

The mean air temperature during the growing season is one of the best measures of climatic suitability. If there is a difference in temperature of only a few degrees between the region where the seed comes from and the place where it is to be used, it is likely to be climatically suited. Length of the growing season, the amount and seasonal distribution of precipitation, and the latitude are other points of value to be considered in comparing climates.

It is practically impossible from inspection of a tree to identify its inherited characteristics as a guide for seed collection. Some exceptions to this statement can be found — spiral grain is considered an inherited characteristic (Champion 1930) — but not all characteristics are inherited from parent trees. Branchiness or distorted form, for example, might be due primarily to the light relation or to injuries rather than to inheritance. Germinative capacity, size of the seed and early size of seedlings which the seed produces, and possession of desirable inheritable characters are the most important points in fixing the quality of tree seed (Baldwin 1942, p. 32). Environment is the chief determining factor as regards germinative capacity of the seed and vigorous development of the young seedlings. Size of seed, when properly employed, has been considered helpful in determining its quality. Large seed from a given locality possesses a greater germinating power and produces more vigorous seedlings than smaller seed from that same locality. It is doubtful that this vigor is more than temporary. Righter (1945) in studying seed of the genus *Pinus* attributed variation in seedling size associated with variation in seed size primarily to difference in size of the endosperm, essentially an environmental rather than a hereditary factor. However, he concludes: " Selection within progenies according to either seed size or seedling size would have no adverse genetic consequences. Therefore it is clearly justifiable to obtain any cultural benefits possibly by culling the smaller seeds or the smaller seedlings."

Seed of any species may vary in size on the basis of locality. Within the range of a species the seed produced in northern latitudes and at high elevations tends to be the smallest. For example, eastern white pine seed from the Lake States is smaller on the average than seed from southern New Hampshire, but the larger seed from each locality should be of good quality. Where artificial reproduction is being used on any operation, except one of very small size or where expense of collection is not a factor, it is as yet impractical to make use of large seed only.

Since good seed is so essential for the success of artificial repro-

duction, the fullest possible information should be obtained regarding every lot of seed which it is proposed to use. Within recent years there has been discussion as to the advisability of having some public agency undertake control of forest-tree-seed certification (Baldwin 1939). In the absence of a strong demand for such a service, about all that is practical in the way of seed certification today in this country is, in buying seed, to require that the place of collection be stated, the geographical location, altitude above sea level, date of collection, and year of crop being given. In addition information should be available as to whether the seed came from a race indigenous to the locality where collected. This last point is less important in the United States today than in some European countries since there have been relatively few places where exotic species, either native to this country or of foreign origin, have been established long enough to produce seed in abundance. Hence practically all seed which is collected is as yet of native races.

Foresters already recognize several strains of Douglas-fir seed within the Douglas-fir region of western Oregon and Washington. This region is less than 500 miles long north and south and averages about 150 miles wide east and west but in elevation ranges from sea level to over 14,000 feet. Kummel, Rindt, and Munger (1944, pp. 13-14) list 9 seed sources or provenances, based on elevation and frost-free period. Each provenance is climatically different from the others, and it is advisable to use for planting seed collected in the same provenance. Yet this may not exclude the possibility of using some of the better strains in the next most similar zone.

Certification as to quality of the seed is also desirable. This should include information as to purity of the seed (indicating the percentage of impurities and damaged seed), the weight of 1000 clean seed, the number of seed per pound, and the germinative energy of the seed.

Germination tests of forest-tree seeds may be made quickly by cutting open a number of seeds. Such tests usually give too high results, often double what can be obtained in actual germination, as they do not identify overdried or overheated seeds or those stored too long. Actual germination in the laboratory is ordinarily needed to obtain an accurate estimate of the germinative energy of most seeds.

If good seed can be purchased, it will usually be advisable to buy rather than collect. Buying has the disadvantage of not giving full control over the selection of trees from which to collect. Unfortunately there are too few good seeds on the market and often seeds must be collected by the forest owner. If possible seed should

be collected locally in places where there is a heavy seed crop and only from sound, vigorous trees. Collecting from felled trees, if a logging operation is in progress, may be cheaper than from standing trees. The seed on young trees can usually be reached more easily than that on large old trees and hence may be cheaper to collect. There is no reason why fertile seed from such trees should not be as good as similar seed from old trees. However, there may be an unusually large proportion of empty seed in the crop on young as compared with old trees, which reduces the yield of fertile seed secured. This point should be investigated before collecting from very young trees. Allen (1942) reports a minimum seed-tree age of 20 years for seed collection by the British Columbia Forest Service but gives data indicating that even younger trees may produce satisfactory seed crops.

The details of collection must be adapted to the type of seed. On the whole the bulk of the artificial reproduction in this country has been of conifers, chiefly pines and spruces. A great deal of black locust is being used for erosion control, but as yet hardwoods have been little employed in artificial reproduction.

Within recent years the use of hardwoods in artificial reproduction has been stimulated by several factors, namely, the development of shelterbelt planting in the Prairie region and erosion-control planting in the south and east (both using hardwoods to considerable extent), and a general feeling that plantations of hardwoods deserved trial. What is said about collection and extraction of seed in the following paragraphs applies to conifer seed and cones unless otherwise stated.

The proper time for collecting cones is just after they have matured. Cones of species that do not begin to open directly after maturing can be left on the tree until later. They must invariably be picked before they start to open; otherwise much of the seed will be lost. It is important not to collect cones before they are mature as unripe seed has lower germinative capacity than seed fully mature.

In most species the cones start to open soon after the seed is mature. If this signal is taken as the time for starting collections much seed will be lost since collection cannot be accomplished in a moment. Some other method of determining maturity is needed. A time-honored plan is to cut cones open and inspect the seed to appraise its degree of hardness. If this is done every few days by a man of good judgment the approach of maturity can be detected with reasonable accuracy. The color of the cones is helpful with some but not with all species and in any event is less accurate than cutting and inspecting the cones. Usually squirrels can be seen cutting and

storing the cones weeks before the time of maturity. Hence the work of these animals cannot be taken as the time to start collection.

An accurate method has now been developed for judging maturity by determining the specific gravity of freshly picked cones. As they ripen, the maturing seed and cones lose water and hence become lighter. Maki (1940) found that a specific gravity of 0.85 was a good figure to use with ponderosa pine, and he advised starting collections when the specific gravity of the cones dropped to this point. The correct specific-gravity value must be determined for each species before applying the method. To apply, a can of test liquid (for which kerosene is satisfactory) is carried to the field and cones are dropped into the can. If most of the cones float seed is ready for collection.

This test for ripeness of cones has been developed further in the Lake States (Anonymous 1940 and 1941), where a testing set of four containers holding respectively water, linseed oil, a mixture of equal parts linseed oil and kerosene, and kerosene is employed to ascertain the approximate specific gravity of red and white pine cones. Color is also considered a good test of ripeness with these species, although more difficult to define and measure.

Seed of conifers after being collected in the cones must be extracted from them. If placed immediately after collection in a dry kiln the cones would casebarden. To avoid this, air curing for 15 days to several months is necessary with most conifers. Exceptions to this general statement can be found. For example Rietz and Kimball (1940) found that red pine cones could be kiln dried immediately after collection without any preliminary air curing in a forced-air circulation kiln. Before this is done the cones usually are allowed to cure by air drying in bins for a few weeks.

With most conifers the application of artificial heat is the effective way to open cones and release the seed. Small lots of cones can be dried by solar heat, but this method is effective only with species whose cones open easily. Where a large quantity of cones must be handled it is desirable to erect a seed-extracting plant. The modern type of seed-extracting plant, as described by Rietz (1936), consists of a kiln through which hot air of any desired temperature is circulated by means of electrically driven fans and in which the humidity can be regulated by the introduction of live steam and by a system of ventilation. The cones are placed in trays stacked one above another, loaded on trucks, and wheeled into the kiln. Accurate control of temperature, humidity, and air circulation enables a kiln of this type to extract more seed per bushel of cones in much less

time and at lower cost than has been possible in kilns previously used.

Another kiln used for extracting seed is of the convection type. This makes use of the tendency for hot air to rise. The hot air is admitted at the bottom of the drying room and passes upward through racks of cones and out through vents in the top. A convection type of kiln is less expensive than the forced-air-circulation type but does not permit as accurate temperature control. Maximum temperatures, therefore, must be lower, and a longer time is required for seed extraction. For small operations or for species whose cones open with relative ease the convection kiln will prove satisfactory.

In extracting seed the time must be kept as short as possible to lessen expense, and yet the viability of the seed must not be impaired. This danger limits the maximum degree of heat which is permissible. The objective is best attained by having the cones air cured and then subjecting them in the kiln to uniform temperature just long enough for them to open, meanwhile keeping the air in the heated chamber as dry as possible. Circulation of hot, dry air must be provided to all parts of the kiln and at the same time provision must be made for removing from the kiln the moisture passing out of the cones. Safe maximum temperatures and length of time required to open cones vary with the different species of seed. For red pine Rietz and Kimball (1940) advised maximum temperatures of 130°, 150°, and 170° F depending upon the type of kiln and the previous treatment of the cones.

If only small quantities of cones are gathered it does not pay to erect an expensive seed-extraction plant. Cones are bulky to ship, and rather than send them long distances crude methods of heating and drying the cones frequently are employed. Eventually a cheap portable kiln may be developed which can be moved around to the locality where the cones are gathered.

After extraction many species of seed must be dewinged and then cleaned of waste material. All this is done by special seed dewingers and fanning mills in the seed-extracting plant. The clean seed is placed in glass carboys or metal containers with sealed tops and kept at temperatures of 34° to 38° F until time for shipment. The purpose is to maintain a low, even moisture content, keep at a cool temperature, and cut off access to the air, thus reducing respiration and transpiration to the minimum. Seed stored in this way retains its viability for several years. Seed of eastern white and red pines may be kept in this manner for at least seven years if the moisture content is reduced to about 5 per cent before storage. Where the

seed is to be used in a few months it is unnecessary that it be kept in cold storage.

Though the method of extracting conifer seed by means of artificial heat, as described in the previous paragraphs, is still the one commonly employed with these species, particularly the pines, there are indications that a cheaper method may be developed. Miller and Lemmon (1943), working with ponderosa pine, extracted the seed of this species in a medium-sized swinging-hammer mill. The cones were run through a hammer mill and pounded into small fragments. In the experiment cited only a small percentage of the seeds were damaged in processing. The equipment needed is much simpler and less costly than dry kiln and the storage sheds commonly used for curing and storing cones. A power unit, a hammer mill, and a seed cleaner all mounted on a truck comprise the necessary equipment. This portable outfit can be taken, if desired, right to the collection site and the seed can be extracted from the cones, dewinged, and cleaned there as fast as collected, doing away with problems of curing and storing the cones. It may eliminate a large share of transportation costs since only the clean seed will need shipment. Seed should be obtained more cheaply than by the kiln method. As most organizations which require large quantities of conifer seed are already equipped with seed-extraction plants using dry kilns, an immediate change in method of extraction is not likely to occur. The hammer method should be tested for other species of conifers used in artificial regeneration and its practicability determined for each important species. If found satisfactory as to quality of seed produced and as to cost of extraction the hammer method may ultimately be widely employed in extracting conifer seed.

The hammer method is already accepted as an excellent method for extracting the seeds of some hardwood species such as black locust.

Since seed years for many important conifers come only at intervals of 2 to several years, continuous programs of artificial reproduction can be successfully prosecuted only through seed storage to provide seed for use in years without a current seed crop. The New York State Conservation Department maintains an underground forest-tree-seed storage plant, automatically cooled, in which is kept always several years' supply of seed for operation of their nurseries.

Extracting hardwood seeds from the fruit is usually a less complicated process than from cones of conifers. After collection (Kellogg 1936) the pods of black locust should be run through a grain separator or some other type of thresher. The seed can be cleaned in a fanning mill if it is not cleaned in the threshing process.

Fleshy-fruited species require a different type of treatment to remove the seed from the fruit. Steavenson (1940) recommends a hammer mill for efficient operations on a commercial scale. In such a mill the pulp is flushed away from the seed by heavy streams of water as the revolving hammers loosen the pulp from the seed. Dry-fruited species, like black locust, can also be extracted with the hammer mill.

While black locust and hardwood seeds of similar character can be stored dry, many other hardwood seeds should be kept moist at temperatures a few degrees above freezing. This is usually done by stratifying the seed in moist sand and burying in a cold cellar or in the ground or by placing in a cold-storage plant.

Information relating to the viability of the seed is wanted by all users of tree seed. It is desirable to know in advance of sowing what may be expected in the way of germination. Tests to determine the germinative energy should be made before the seed is sown, and, if the seed is purchased, it should be bought on a warranty as to the germinative energy. This term is understood to mean the percentage of the seed that will germinate promptly when sown. Seed that will not start quickly under the favorable conditions of the tests is of low value and cannot be expected to do well when sown in the open. Only quickly germinating seed has a chance of meeting competition and producing vigorous seedlings.

Germination tests can be made in the greenhouse in sand or prepared soil and in special germinating apparatus, where the seed is placed between blotters and kept moist and warm. Germinative energy is figured on the basis of the number of seeds germinating during the period of most active germination (usually 7 to 35 days after the start of the test), in relation to the total number of seeds used in the test.

Experience shows that even the percentage secured in the greenhouse tests will be too high as a measure of the actual number of seedlings starting in the open. How much too high the percentage will be depends on the quality of the seed and upon the soil and climatic conditions in the open.

Seed is kept in storage from a few weeks up to several years and then, when needed, is sent either to the field for direct seeding or to the nursery for the production of nursery stock.

Nursery Operations. The first consideration in growing forest-planting stock is the selection of a suitable location for the nursery. It should be located within the region to be planted on a site where the soil thaws out a little earlier than the areas to be planted, thus

guaranteeing that the nursery stock can be dug as soon as needed for planting. If conifers are to be produced the soil should be of the sandy-loam type, deep and moist and always well drained. This will also be good for hardwoods, although a somewhat heavier soil may be used for them. An acid rather than an alkaline soil is best for conifers. Level land free from stones is essential, at least where low production costs are a requisite. There must be an adequate supply of reasonably pure water which can be piped into the nursery. Availability of electric power and a good supply of labor is desirable. If the stock is to be shipped by rail, location near a railroad is essential. In any case the nursery should be adjacent to a good road.

The size of the nursery should depend upon the number, size, and kinds of the plants which will be needed each year and the methods of growing the plants and managing the nursery. To grow forest-planting stock cheaply a large volume of output running into millions of trees a year is essential. The business is so complicated and its success hinges so vitally on the accurate application of a highly specialized technique, requiring constant vigilance and variation in its application, that skilled men must be in control. Only nurseries with a large output can afford to employ men competent enough to assure the production of good stock at low cost. Nursery management in practice is essentially a local problem; successful methods can be worked out only by experimentation within each nursery.

Where only a small amount of planting is to be done it usually is best to buy the planting stock rather than to start a nursery. At the present time the production of forest-planting stock is to large extent in the hands of state- and federal-owned nurseries, some of them very large.

The first operation after a nursery is started, and the necessary improvements such as buildings and a water system have been installed, will be the sowing of the seed. Two methods are in common use: in one the seed is sown broadcast in beds usually 4 feet wide and running any desired length; in the other the seed is sown in drills usually running lengthwise of the same sized beds. Between the 4-foot seedbeds, paths 15 to 24 inches in width are left. In some nurseries it has been found advisable to put up a board curbing along the sides of the beds to protect the edges from trampling. The curbing is used especially in broadcast seeding in cases where protection with wire netting against birds and rodents may be a necessity.

Conifer seeds were until recent years principally sown broadcast, but lately the trend has been toward drill sowing, largely for economic reasons. Seeding machines have been developed which sow the seed

in drills, cover it to the desired depth, and roll the beds all in one operation, greatly reducing the cost of sowing. Drill-sown seedbeds can be cultivated at least partly by machinery, thus effecting a further saving in cost over broadcast-sown beds which must be entirely hand weeded. Various seeders have been developed for sowing forest-tree seeds. J. O. Hazard, State Forester of Tennessee, developed a seeding machine which is manufactured and distributed by the Kirby-Williams Steel Works, Jackson, Tennessee. Huberman (1935) modified this seeder for the purpose of sowing longleaf-pine seed, and McComb and Steavenson (1936) perfected a seeding machine for use with black-locust and other hardwood seeds. Only for a large nursery would the investment in these seeding machines be justified. Drill sowing is often done by hand tools in small nurseries, using a variety of simple home-made equipment for making the drills and distributing the seed. Drills usually are spaced from 4 to 12 inches apart, depending on the species sown, the method of cultivation used after the seeds have germinated, and the density of stocking desired in the seedbed.

Broadcast sowing of seed in the nursery is done by hand. In accomplishing this, care must be taken to distribute the seed uniformly. Experience is needed to obtain an even stocking. To assist in obtaining uniformity the seed should be divided into small lots and each lot sown on a given small unit of area such as a 4- by 12-foot section of seedbed. After broadcast sowing seed must be lightly covered in a separate operation. It is advisable to use sand for covering the seed both to avoid any crusting of the top soil and to lessen the danger of certain fungi attacking the seedlings.

One of the advantages claimed for broadcast sowing was that denser, more evenly stocked stands were secured. Today the effort is to grow seedlings at a lower density of spacing and obtain bigger plants. The drill sowing is successful in accomplishing this. Lower density can also be obtained by broadcasting a smaller amount of seed per bed and by thinning the seedlings. Both seeding in drills and broadcast seeding are satisfactory methods of sowing. Which to use should be decided for the individual nursery on the basis of local conditions and requirements. Hardwoods are customarily sown in drills, although there are exceptions to the rule.

In sowing seed the amount needed per square foot of bed surface should be carefully figured out. This depends on the species and the germinative energy of the seed, discounted for the actual number of seedlings which it may produce in the seedbed. A certain standard should be set up for each species, representing the number of seedlings

wanted per square foot of seedbed. This may be as low as 20 per square foot for longleaf pine or as high as 200 per square foot for some of the hemlocks and spruces. The seedling density depends not only upon the light and space requirements of the species but also upon whether the stock will be field planted when one, two, or three years old, or will undergo one or more transplantings before being placed in the field. Seedlings intended for direct field planting should have 40 to 100 per cent more room than those grown for transplanting. A convenient formula for computing the amount of seed to sow in a seedbed reads as follows: $P = \frac{A \times D}{G \times S \times Z}$ in which $P =$ pounds of seed, $A =$ area in square feet, $D =$ number of seedlings desired per square foot, $G =$ germination test in percentage, $S =$ number of seed per pound, and $Z =$ a variable factor expressing the difference between the germination secured in the tests and that secured in the seedbeds (Olson 1930).

The seed sowing may take place either in the spring or in the fall, or, if the ground is not frozen, as in the Gulf states, in the winter. For slow-germinating species like white pine and for seeds that should be kept moist like the true firs, fall sowing gives superior results. Seeds sown in the fall are exposed to rodent attacks for a longer time before germination, and also, if a warm period follows the fall sowing, the seed may germinate immediately and perish. In fact some species may germinate so promptly after sowing as to make fall sowing impracticable. On the other hand, with many species, seed sown in the fall germinates earlier in the following spring than spring-sown seed and for this reason often suffers less loss from damping-off fungi. Seedlings from fall-sown seed are more vigorous and the beds contain fewer weeds than spring-sown beds. Fall sowing has the advantage of better distributing the necessary nursery work by taking seed sowing out of the busy spring season.

Each species of seed may require special treatment to ensure prompt germination. This treatment in many cases consists only of proper storage after collection and extraction of the seed to complete after-ripening, or it may include such details as scarification of an impermeable seed coat, or moist stratification a few days or weeks before sowing to hasten the intake of moisture. For example, black locust seed should be scarified before sowing, while eastern white pine, when spring-sown, will germinate better if stratified in moist sand for 20 days at temperatures a few degrees above freezing.

After conifer seed are sown the beds usually are covered with long

strips of burlap, or a mulch of straw, pine needles, or other material, until the seed germinates. In some regions it is necessary to protect the seed and newly germinated seedlings from rodents and birds by covering with fine wire netting; in others, this rather expensive protection is not needed.

One of the largest sources of expense in seedling production is the weeding, which is necessary several times a season. After broadcast sowing weeding has to be done by hand, but with drill sowing much of the weeding can be accomplished by machines. To lessen this expense efforts should be made to reduce the amount of weed seeds in the nursery, by using only mulches of material relatively free of weed seeds, by composting manure, and by destroying weed seeds and weeds before they produce seed. Seedbeds may be burned over with a flame-throwing torch, after sowing but only a few days before the tree seeds germinate, with the object of destroying weed seeds on the surface. There is danger that tree seeds as well as weed seeds may be destroyed if too much heat is developed. Surface burning may also be used before sowing. The seedbeds are prepared early; 2 to 3 weeks later the surface is burned with a flame-throwing torch, and the seed is then sown immediately without disturbing the bed surface. Wells (1940) states that the costs of weeding in one nursery were cut approximately one half by such treatment.

Chemicals have been used successfully in some instances to eradicate weeds (Wahlenberg 1930), but in other cases losses from reduced germination of tree seed and injuries to seedlings more than offset reduction in the weed crop. Although chemicals such as zinc sulphate, copper sulphate, and sulphuric acid undoubtedly reduce the number of weeds and injure their development, yet they must be used only experimentally in any given nursery until their effect upon tree seed and seedlings has been established.

Shading of sensitive species of conifers during their first year in the seedbed may be necessary. If so, it is accomplished by placing over the beds about a foot from the ground a screen of lath widely spaced to give half shade. Hardy species may develop better uncovered In cold climates it is necessary to cover the seedbeds in the fall of the first year in order to prevent frost heaving during the winter. This cover can be mulch, burlap, or other convenient material. It must be taken off promptly in the spring as soon as warm weather comes, or the seedlings may mold.

Watering of seedbeds usually is necessary during the first season. This can be done most cheaply and effectively, so far as the distribution and penetration of the water into the soil is concerned, by means

of either an automatic-sprinkler system, or the rotary type of sprinklers used on lawns. The former is preferable. Watering not only supplies the seedlings with the moisture essential for their growth but also has the effect of reducing soil-surface temperatures. Where such temperatures are likely to rise dangerously high for sensitive seedlings, watering in the middle of exceptionally hot days may be helpful in checking heat injuries. The old idea that seedbeds would be seriously injured if watered in the hot sunlight is not correct.

Where seedlings are left more than one year in the seedbed, there is relatively little work during the succeeding years, since the density of the seedlings is so planned that they close together after the first year.

Machines for digging seedlings and thereby cheapening costs as compared with hand digging, have been developed. The principle employed is to pull a metal blade under the seedbed thus severing the roots. The blade is not horizontal but is set at an angle which lifts the seedlings somewhat. Men follow the digger and pull the loosened seedlings from the soil. One example of a tree-digging machine used in the New York State nurseries is described by Lewis and Eliason (1937). These tree diggers usually can be employed for lifting both seedlings and transplants and, in some cases, with a horizontal blade, are useful for root pruning.

Nursery stock is classified as either seedling, if grown from the seed and not moved while in the nursery, or transplant, if taken up and reset in the nursery one or more times. The age and character of nursery stock are designated by two figures, the first showing the number of years which the stock grew as seedlings and the second the number of years which the stock grew as transplants. For example: 1–0 means that the stock is one-year-old seedling since it has grown one year as seedling and has not been transplanted; 2–2 means that the stock is four-year-old transplant since it has grown two years as seedling and then two years as transplant.

Sometimes the season of sowing is indicated by prefixing the letters *F* or *S* (for fall or spring) to the seedling age, and treatment by root pruning may be shown by affixing the letter *P* to the seedling or transplant age.

When sturdier stock than can be produced as seedlings is needed, the seedlings are dug up and replanted in the nursery. This process is known as transplanting. Transplanting has the effect of making the root system more compact and the top more stocky since the transplant is given more space to grow in than the seedling. The top may be shorter than that of a seedling of the same age, but it

will be sturdier. A fibrous root system big in relation to the portion of the plant above ground is desirable in forest-planting stock and usually is secured in highest degree in stock which has grown for one year in the transplant bed. Where exceptionally tall, bushy planting stock is wanted trees that have stood widely spaced for two years in the transplant beds should be grown. However, these transplants probably will not be so well proportioned between roots and top as the younger transplants.

A type of seedling stock known as root-pruned seedlings is developed in some nurseries. It is intermediate between seedlings and transplants. Root pruning is done, while the seedlings are still growing in the beds, by means of a horizontal knife or blade drawn under the surface of the ground by a tractor or other source of power. The root pruning is a rather delicate operation and must be done at just the right height and at the right time of the year in order to prove worth while.

The purpose of root pruning is to force the seedlings to send out a better system of fibrous roots, instead of a long sparse root system, and to form a short, stocky top. If a compact root system can be developed without transplanting, considerable expense may be saved. Root pruning may be applied as an operation to cut off the roots at a designated level, either leaving the stock so treated in place to grow for another year, or lifting the stock in the same operation. Root pruning is done usually at depths of 4 to 6 inches below the surface, although it has been as shallow as 1½ inches and as deep as 9 inches. In some nurseries the practice is to root-prune, for the purpose of retarding growth, all stock that may have to remain in the nursery one or more years longer than originally intended because of shortage of labor or funds for field planting. Some nurserymen are already convinced of the practicability of producing root-pruned seedling stock that will compare favorably with transplants and cost much less to grow in the nursery.

Transplanting of small seedling stock is effectively handled by placing the seedlings in transplant boards 6 to 10 feet in length which have notches at short intervals, usually 1½ or 2 inches, in which the individual plants are placed. When the board is full the trees contained are planted as a unit in a prepared trench. One man can transplant more than 5000 seedlings per day in this way. The transplants are set out in beds the width of the transplanting board or in solid blocks of any convenient length and width. The distance between transplant rows should be determined by the method of cultivation, either hand or machine, to be employed.

Eventually machines for transplanting seedlings may be developed which will reduce the cost of transplanting as now carried on with transplant boards. Hildebrand (1943) described such a machine in which a celery planter was altered to permit close spacing within the rows and between the rows necessary in forest-nursery transplanting. This machine has been successful in transplanting small seedlings in the sandy soils of Michigan. Undoubtedly, a machine to operate efficiently must be especially designed for the prevailing soil and type of topography.

It is important that transplanting be done as early in the growing season as possible before new growth appears. The period suitable for the work is limited to a few weeks. Fall transplanting after the season's growth is completed, although sometimes possible, is under most climatic conditions more hazardous than that done in the spring.

Transplanting in late summer (July and August) has been successful in some nurseries. It has the advantage over fall transplanting of enabling the newly transplanted trees to get their roots well established before winter. There must be facilities for watering summer-transplanted trees or else a climate with abundant summer precipitation.

Ordinarily no shading or watering of the transplants is necessary. When ready for digging the transplants may be dug with the same digging machine used for lifting seedlings. Conifers customarily are dug just before the planting season. Methods of storage which permit digging conifer seedlings and transplants in the fall and holding them safely in storage until the planting season, have not as yet been developed on a commercial scale although considered a promising possibility. Hardwood stock may be dug either in the spring or in the fall and kept in storage over winter.

In shipping nursery stock to the field for planting, a wide variety of containers have been used. The points to emphasize in shipping are that the roots should be kept moist and the tops should be open to the air so that they will not become heated. Probably the container most typical of the forest-nursery industry is the tight roll of planting stock with the tops open to the air at each end and the roots of opposite facing bundles overlapping. The roots are protected by moist sphagnum moss or shingle tow and are wrapped in water-proof paper and burlap. The bundle is made rigid by wooden cleats and is drawn together and bound with wire in a bundling machine.

Protection of the seeds and of the plants in the forest nursery demands constant vigilance and quick action. The seeds may need protection against rodents and birds from the time they are sown

until they germinate. Screening of the seedbeds provides the most effective control but is expensive and in many cases not essential. Birds are often very destructive for the short period when the cotyledons of the young seedlings are still partly within the seed. Sometimes patrol with shot guns may be successful in reducing the depredations of birds, which usually are injurious only for a short time when the seedlings are very young. Where mice are the principal rodents involved, systematic poisoning of the nursery area often minimizes the damage and is a necessary precaution.

After germination, seedlings are commonly attacked by damping-off fungi active in the surface soil, which may destroy the young plants in wholesale fashion. When serious these fungi must be controlled; this can be accomplished by treating the seedbeds before, or at the time of, sowing with various acid solutions, such as sulphuric acid, formaldehyde, aluminum sulphate, and others which have been found effective in a given nursery. Dry Bordeaux mixture is sometimes successful in checking damping-off. Covering seed with clean, relatively sterile sand tends to reduce damping-off. Fall sowing of seed, which encourages early spring germination and produces relatively sturdy seedlings by the time hot, humid weather comes, is also of assistance.

Among the most troublesome of the numerous insect enemies of nursery stock are the white grubs (*Phyllophaga* spp.). They are so prevalent on grass-covered areas that such land should never be used for nursery stock without one to several years of preparation. The grubs found in cultivated land are less frequent. The best methods of control consist in clean cultivation and in allowing areas infested with grubs to lie fallow for a year or two. Where land is needed immediately, treatment of the soil with arsenic will control the grubs, but this treatment involves so much danger of severe burns to the nursery stock that it is not advised for forest nurseries. Treatment with paradichlorobenzene at the rate of 400 to 500 pounds per acre is practiced by New York State Conservation Department to control white grubs at the Saratoga Nursery (Eliason 1939).

In every forest nursery there are sure to be other insects and fungi, characteristic of the locality, which appear suddenly and which the nurseryman must learn to recognize, must be on the lookout for, and must be prepared to combat.

Climatic injuries from frost, heat, and drought should be expected frequently as the seasons pass. They are combatted chiefly by the nursery routine of covering, shading, and watering the plants.

So far nothing has been said as to fertilizers for nursery stock.

Evidences of lack of fertility may be seen in the condition of the young trees, such as their slow growth and lack of the normal color. However, unhealthy condition of nursery stock may be brought about by so many other agencies besides inadequate fertility as to require careful study in each case before the primary cause is made clear. Fertilization is an important matter in the forest nursery, since in digging nursery stock both tops and roots are removed from the area and practically none of the nutrients taken from the soil are returned. All types of fertilizers are of value but usually there are a few which prove best for a given nursery. To illustrate, in some cases leaf litter gathered in the forest nearby has proved a cheap and efficient fertilizer (Lanquist 1945); in others a compost of organic residues and commercial fertilizers has given satisfactory results (Muntz 1944). Availability and cost of different fertilizers are influential in determining the kind to use. Furthermore the requirements for maintaining soil fertility are not the same in all places or for all species. The problem of fertilization is a local one and needs careful study in each nursery. Maintenance of soil fertility by plowing under humus-building and nitrogen-fixing cover crops should be practiced. One thing is certain that without wise use of fertilizers and soil-conserving practices good nursery stock cannot be produced year after year.

Artificial Reproduction by Direct Seeding. Artificial reproduction by direct seeding is accomplished by sowing the seed right on the area to be reforested. The other common method of artificial reproduction consists in planting the area to be forested with young trees grown from seed in a nursery.

In direct seeding the seed is sown under conditions much less favorable than in the nursery, and success is uncertain. A much denser stand of seedlings must be established in the beginning by direct seeding in order to ensure as good a stand ultimately as could be obtained by planting. Where direct seeding is used, enough seed should be sown to result in the establishment of at least 2000 to 5000 well distributed young plants per acre.

Silviculturally, direct seeding, since it provides through its denser stand for greater variation and selection among genotypes, may result in a better stand than planting. This point has more value if large numbers of seedlings start, 100,000 or more per acre for example, as may occur in natural reproduction. The expense involved of obtaining such a stand by direct seeding is prohibitive with most species in this country. If a stand of 2000 to 5000 plants per acre is secured by direct seeding, in contrast to 500 to 1500 by planting, the chances

for better natural selection of genotypes is not so much greater in direct seeding than in planting, particularly when the practice is followed by discarding the weaker trees in the nursery and planting only the best individuals. In theory a more natural root development is secured, since the young plants are not moved after germination. How important this may be in practice is open to question.

From the practical standpoint it is more difficult to obtain success in direct seeding than in planting, because the small seed in contrast to a strong nursery-grown plant must struggle against unfavorable climatic conditions and compete with other, often overtopping, vegetation. Another thing to consider is the loss of time caused by using direct seeding instead of planting. The greater the age of the planting stock, standard in a given case, the more time lost by starting with seeds instead of plants. Even if 1–0 planting stock can be used, more than one year really is lost since it will take longer for seed scattered on the ground to germinate and for the seedlings to gain the size attained in a similar time in the nursery. Only on sites where conditions for germination and early survival are favorable should regeneration by direct seeding be attempted. On such areas the relative cost of seeding versus planting may be the determining factor between the two methods, although initial cost should not be the only consideration.

In most parts of the country direct seeding of conifers has so far proved to be a more expensive and less certain method of artificial reproduction than planting. This may be attributed partly to failure to develop the right technique for obtaining adequate survival without high cost, which by further experimentation may be remedied, and largely to the low cost at which nursery stock, capable of high survival when planted, can be produced in many parts of the country.

In order to reduce expense in direct seeding, seed usually is scattered on only a fraction of the whole area. The method most suitable for this country is known as seed spotting. The seed is dropped on spots spaced at the same intervals that would be used in planting the area. A number of seeds are placed in each spot.

On sites where loss of seedlings from exposure to sun and wind and from aggressive competitors is anticipated the seed spots should be spaced at irregular intervals rather than at a fixed distance apart. If this is done sheltered spots can be chosen to take advantage of available shelter from logs, stumps, and stones and to avoid undesirable competition of other plants. The chances for success will be greater if the spots are freed (often termed " scalped ") of grass sod or other surface vegetation, unincorporated humus, or litter before the sow-

ing and the seed is then dropped on the mineral soil and lightly covered with soil. Such treatment adds to the expense but is likely to be a significant factor in increasing germination and survival. In preparing these seed spots the tendency is to create a depression slightly below the level of the surrounding surface. This should be avoided, particularly with species whose juvenile growth is slow, as even on level ground leaves are likely to be blown into this depression and form a layer smothering the tiny seedlings. The danger of seed spots accumulating debris of various sorts is enhanced if they are depressed.

Another way of accomplishing direct seeding of an area is to plow lines one or two furrows wide at intervals of 4 to 8 feet and do the seeding at 4- to 6-foot intervals in the furrows or sow the entire length of the furrow. Where the land can be easily plowed, this may be cheaper than the usual seed-spot method.

The tools used in direct seeding range all the way from hoes, small rakes, dibbles, and garden drills to seeding guns of the corn-planter type. One of these guns is recommended by Woods (1945) for use in the Douglas-fir region.

Broadcast sowing of seed, to be successful, requires so much seed as to be relatively expensive compared with seed spotting even though less labor is needed. Furthermore, to obtain a satisfactory survival of seedlings after broadcasting will usually require covering the seed in some way to keep it moist and hidden from birds and rodents. This can seldom be done at reasonable cost on the average area needing reforestation. Broadcast sowing requires many thousands of seed per acre. With seed of large size and consequently relatively few to the pound many pounds of seed may be needed per acre. With seed of small size, such as those of black spruce, the amount in pounds of seed needed to broadcast an acre is much reduced. Furthermore the necessity of special work to cover the broadcasted seed is less urgent as the size of the seed decreases. Hence for small-seeded species direct seeding by broadcasting instead of by sowing seed spots may prove useful.

Some hardwood species can be regenerated successfully by direct seeding. Heavy-seeded species, like the oaks, fall into this class. The work is best accomplished by the seed-spot method. Large seeds of this type contain abundant reserve food and their seedlings are not so likely to perish for lack of moisture as those developed from small conifer seeds.

Destruction of the seed by rodents is a common cause for failure in direct seeding both of hardwoods and conifers. Control of rodents

is a difficult and expensive part of the cost of direct seeding and may often prove the deciding factor against this method. Systematic poisoning of the area before seeding should result in protection to the seed, although the size and shape of the area to be reproduced, and its relation to adjoining unpoisoned areas, may be influential in determining the effectiveness of the poisoning operation. Coating seeds with repellents or poisons has not usually proved thoroughly effective. Many rodents may be killed by eating the poison — but only after they have eaten the seeds. Recent large burns may be a favorable place for direct seeding as the rodents may be temporarily gone or reduced in numbers. However, this point needs further investigation. Munger and Matthews (1941) state that, on some areas, burning of slash in the Douglas-fir region apparently has encouraged small rodents by making tree seed more available on the exposed ground.

Another way of controlling the depredations of rodents is by placing a wire cage or dome of hardware cloth over each seed spot. This method of protection has been tried in various parts of the country and has merit provided the cost can be kept to a reasonable figure. Keyes and Smith (1943) have developed a technique for manufacturing wire domes cheaply and using them to protect seed spots in northern California at an estimated cost of slightly more than 0.25 cents per seed spot.

The wire domes may influence (favorably for germination and seedling survival) light intensities and soil temperatures on the surface covered. Wire cages, though effective against birds and small rodents if properly secured in the ground, may be overthrown by larger rodents and other animals.

Pregermination or sprouting of seeds before they are sown may reduce the amount of damage done by rodents for two reasons: first, the time required for the seed to develop into a seedling unattractive to rodents is shortened; second, it is believed that, in some cases at least, the chemical changes taking place in the germinating seed may make the sprouted seed less palatable to the rodents than one not so far advanced. For example less loss would be expected in sowing red oak acorns in which germination had progressed so far that the radicles extended approximately ½ inch out of the acorns than in sowing acorns without protruding radicles. Stratification of seed in a moist media, such as sand or peat, to hasten germination after sowing may not only shorten the time during which the seed is a prey for rodents but may also result in less mortality from climatic causes. An experiment by McLintock (1942) indicated that stratification of seed, before direct seeding, of Virginia, shortleaf, and pitch pines

improved germination and catch (percentage of stocked seed spots) as compared with direct seeding of unstratified seed. The reasons for this result are considered to be increase in the actual number of seeds which germinated and advance in time of germination from late to early spring. McLintock concludes: "These results indicate that for these three species, in the Central States, stratification removes much of the hazard from direct seeding as a method of reforestation and on favorable sites makes it unquestionably feasible and practical."

If seeds are sown in the fall and have several months, before time comes for germination, to come into close contact with the soil and take up moisture, germination comes earlier and is usually better than with spring-sown seed. However, danger from rodents often makes fall sowing inadvisable, and as a substitute stratification before spring sowing may be practiced.

The control of rodents is still in the experimental stage and must be solved locally before direct seeding becomes a safe operation in a given locality.

A thorough study of the possibilities of direct seeding in the western white pine region, on a scale large enough to give results for economic use, was initiated by Schopmeyer (1939 and 1940) and reported upon by McKeever (1942). The lessons to be learned from these experiments are of sufficient interest and possible application elsewhere to warrant brief discussion. Conical wire screens furnish a successful, though relatively expensive, method of protecting western white pine and ponderosa pine seed from destruction by rodents. A poisoning method effective against mice and chipmunks, developed by Wildlife Research Laboratory, Fish and Wildlife Service, proved when applied with western white pine to be less expensive and more practical in application. As described by McKeever (1942*a*, p. 2) this method "consisted of two steps: (1) ten to fourteen days before sowing, the selected area was poisoned with hulled sunflower seeds, treated with thallium sulfate, by distributing the poison-bait where rodents could readily find it in small piles at intervals of 15 to 20 feet under cover of down timber and other debris to protect seed-eating birds from it; (2) the pine seeds were coated a few days before sowing with a poisonous mixture consisting of yellow dextrine, plaster of paris, cornmeal, and strychnine alkaloid." Approximately as good results are obtained when the poison coating is omitted. The seed is sown in seed spots 7½ to 8 feet apart, approximately 20 seeds per spot, and covered with ⅜ inch of mineral soil. Costs of direct seeding, on an administrative rather than an experimental basis, using this

method of rodent control and obtaining comparable survival amounted to less than 75 per cent of average planting costs. The same study brought out the fact that, for Engelmann spruce and western redcedar, direct seeding may be successful on the better sites without any protection from birds and rodents. The seeds of spruce and cedar are so small that they are apparently less attractive to these animals. Western redcedar is a valuable species, and in the western white pine region not easy to raise in the nursery with good survival after planting, hence direct seeding may prove to be the best method of artificially establishing this species. Since Engelmann spruce planting stock is more costly to produce than that of the pines, direct seeding is advantageous for this species. On an experimental basis, direct seeding of Sitka spruce, western redcedar, and western hemlock has proved successful from the standpoint of both cost and survival in the fog belt of the Pacific Northwest (Isaac 1939). Nevertheless practically all artificial reproduction which is carried on in this territory is accomplished by planting.

Shirley (1937) investigated direct seeding in the Lake States region and found that under certain conditions direct seeding could be successful, although he could not at the time recommend seeding as an alternative to planting because seeding was unsuited to areas with many rodents or with dense competing vegetation. However, direct seeding may be advisable at times of labor shortage or lack of planting stock. Direct seeding in the Lake States is advised only on sandy soil with comparatively little and low cover. It should be done in large spots scalped free of unincorporated humus and sod, or in plowed furrows. Shirley found poisoned bait, repellents, and poisoned seed relatively ineffective in protection against rodents and birds, and he considered screens of hardwood cloth the best protection. He reports seeding of jack pine in furrows with a garden seed drill to be a cheap method of artificial reproduction. He advised ¼ pound of seed per acre and reports the work of seeding as much faster than planting. Total cost of seeding jack pine was only ½ or ⅓ that of planting.

Stoeckeler and Sump (1940) advise direct seeding on sandy plains in the Lake States with permanent water table at 2 to 5 feet below the surface and having fluctuation of not more than 2 feet during the year. Such soils have 2 to 4 per cent more available moisture in the top 6 inches of soil than where the water table is lower. This higher moisture content has a favorable effect on soil-surface temperatures, reducing the maximum to 100° to 120° F while elsewhere it may be 140° to 145° F, or so high as to kill the small seedlings. It is sug-

gested that mixtures of black and white spruces, and jack, red, and white pines can be developed successfully by direct seeding on such favorable sites.

All these examples of direct seeding indicate that, given favorable site conditions with development of locally adapted technique and methods of controlling rodents and birds, this method of artificial reproduction can be successful.

Artificial Reproduction by Planting. Planting will be the method generally employed for the present because of the greater uncertainty of success in direct seeding and the consequent higher expense of obtaining the desired density of stocking.

After decision has been made as to the species which will be planted, the next questions concern the age and size of the stock and the number of trees per acre. These two questions are interrelated, since the younger and smaller the trees planted the larger must be their number in order to ensure the desired stocking.

Costs of growing and planting nursery stock rise with increased age and size. Survival, however, is usually better with the larger trees, because the small trees possess less reserve vitality and cannot compete so well with other vegetation. The depth to which the soil dries out is influential in determining the size of stock which should be planted. It is necessary to set out stock with long enough roots so that when planted the roots will reach deep enough in the soil to be below the desiccated topsoil layers during the dry season. Hence 1–0 or 2–0 seedlings, although cheaply grown and planted per thousand trees, may survive so poorly and consequently require such a large number of trees per acre to equal the survival obtained with 2–1 transplants, as to make a seedling plantation more expensive per acre than one composed of transplant stock. On the other hand this situation may be reversed. For example Chapman (1944) in planting shortleaf pine in the Missouri Ozarks found that, although survival percentage of 1–1 transplants was higher than that of 1–0 seedlings, the relatively cheap production costs of the latter stock together with reasonably good survival made 1–0 seedlings the preferable stock for all sites except where competition from existing ground cover would be very severe.

In planting small trees there is less interruption in growth and less liability of injury to root systems than with larger trees. Small trees are relatively thin-barked and may be injured by high temperatures near the ground level that would not hurt larger planting stock, which is better insulated against heat, both by its thicker bark and by its wider and denser-foliaged crown. Trees with very short tops

may be so easily covered with fallen leaves, eroding soil, or other debris as to be unsuitable on some sites in some places.

The question of young, small stock versus older and larger trees is essentially a local problem and must be settled for each site and for each species planted. Poor soils, exposed sites, and areas on which competing grasses and other vegetation are dense usually require big stock, whereas areas without competing vegetation, particularly on good, moist sites, often may be successfully reproduced with small seedlings. The more difficult the conditions for survival after planting, the larger or stronger must the plants be when set out. In an experiment in the Lake States with red pine Rudolf and Gevorkiantz (1935) found that the survival of 2–1 transplants was 23 per cent better than that of 2–0 seedlings. They reached the conclusion that on poorer sites the 2–1 stock was more economical, but on better sites the 2–0 stock planted more densely should be preferred. Root-pruned seedlings may in some cases prove to be superior to ordinary seedlings and to transplants. For Douglas-fir in the Douglas-fir region Kummel, Rindt, and Munger (1944, p. 92) favor 2–0 root-pruned stock over 1–1 transplants because it will produce a satisfactory plantation at a lower cost.

Recent experiments indicate the possibility of coating forest-planting stock with a protective covering of lanolin or commercial wax thereby decreasing evaporation from the trees and increasing their percentage of survival. The Allegheny Forest Experiment Station in their annual report for 1944 (pp. 32-33) indicates that such coatings put on seedlings of white, loblolly, and red pines may result in 15 to 20 per cent greater survival under moderate drought conditions and at a cost of not more than 10 cents per thousand seedlings.

In addition to classifying planting stock by the number of years spent as seedling or transplant, grades are often made within a given class of stock. For example, southern pine 1–0 stock may be divided into three grades based on the sturdiness and characteristics of the plants (Wakeley 1935, p. 77). Trees of grade 1, the best stock, have stout, woody stems with well-developed bark and range in height for slash pine from 10 to 16 inches, for loblolly pine from 8 to 14 inches, and for shortleaf pine from 6 to 12 inches. Grade 1 longleaf pine has practically no stem above ground but possesses a thick taproot $3/16$ to $1/2$ inch in diameter at the ground line with good, covered winter buds and vigorous fascicled needles 10 to 18 inches in length. Grading planting stock by the caliber of the stem is most commonly applied to hardwoods.

The usual types of conifer planting stock are the 1–0, 2–0, 3–0, 1–1, 2–1, and 2–2 classes. Hardwood planting stock is chiefly 1–0.

One of the advantages of artificial over natural reproduction is that the number of trees per acre in early youth can be more easily regulated. In theory the trees should be planted at such intervals as will ensure, after allowing for expected mortality, early development of a closed canopy (5 to 15 years after planting), yet will not result in too serious competition between the individual trees, and finally will produce trees of the size, form, and quality demanded by the management objective.

The question of whether early thinnings will be made has bearing on the spacing to be adopted. If such thinnings will return at least the expense of the operation, or if an investment in early thinning is considered practicable, spacing may be closer, to obtain the benefit of quick creation of a crown canopy, than where such thinnings are impracticable.

Where artificial pruning is practicable and can be carried on without injury to the trees, very wide spacing may sometimes be employed. The cost of the pruning (abnormally high because of the large limb diameters resulting from wide spacing) may be more than offset by the saving in planting costs. Cost of planting has an important influence in determining spacing, since it is a direct function of the spacing and is increased rapidly as the spacing is made closer.

It is evident that choice of spacing must be a local decision based on such considerations as site, growth habit of the species, class of stock planted, survival expected, management objective, and silvicultural treatment to be applied. Spacings not closer than 6 by 6 feet and not wider than 8 by 8 feet will usually be adopted. Planting primarily for erosion control may be as close as 3 by 3 feet in order to obtain rapid development of complete crown coverage and a forest floor. Where Christmas trees are the main product, 4- by 4-feet spacing often is employed. For naval-stores products the rapid-growing slash and longleaf pines may be planted 10 by 10 or even 12 by 12 feet apart to develop relatively deep, wide crowns.

The best time for planting is during the dormant season, preferably only a short time before growth is resumed. If this point is observed the newly established tree will have only a short while to wait before root growth begins and moisture and nourishment can be obtained from the soil. One disadvantage of fall planting is that the tree must wait a relatively long time before its roots start to grow. With conifers (which retain their foliage all winter) evaporation from the

top may result in death or serious injury if the tree is unable to take in water through its roots for several months after planting.

Plantings should be arranged so as to be accompanied or promptly followed by the rainy season, as a plentiful supply of moisture for newly established trees is essential for survival.

Early spring, as soon as the frost has left the ground, is the most usual time for planting in climates where the ground freezes in the winter. Spring planting should be finished before top growth actively begins. The spring planting season can be lengthened by holding the stock in cold storage for the purpose of delaying initiation of active growth. This procedure has so far found chief use in the central and Lake States (Anonymous 1936). Fall may be a good season in which to plant in regions, and on soils (of sandy texture), where danger of frost heaving during the winter is slight. Plants set out in the fall do not become so firmly anchored and acclimatized before winter as do those planted in the spring, and hence they suffer more injury from frost heaving and winter cold the first year. They are also more susceptible to damage by root rot. A great advantage in fall planting, which leads to its use wherever it can be done successfully, is the better distribution throughout the season of nursery and planting operations, which tend to be concentrated in the spring months. In the Gulf states the best planting season for southern pines comes in December and January. Cottonwood can be planted to best advantage in the lower Mississippi River Delta during the month of February.

It may prove advisable to prepare the site before planting. Such work often is unnecessary and can easily be made too costly. Plowing and cultivating the entire area before planting is too expensive in this country at present prices for forest products, although sometimes done elsewhere. However, there will be many places where a reasonable amount of plowing should prove practicable as a site-preparation measure. Where plowing can be done cheaply, as on open, level, sandy lands, it may be worth while to plow wide furrows in advance of planting. This often cheapens the actual cost of planting and by removing some vegetative competition increases survival. Such treatment forms a part of the furrow method of planting, mentioned later in the chapter. Special plows drawn by crawler-type tractors have been developed, which permit the construction of plowed furrows at least 1½ feet wide through grass sod, shrubby undergrowth, and groups of small saplings, at reasonable costs.

In constructing furrows the double moldboard plow used overturns

a layer of sod on either side of the wide furrow and deposits the top soil upon the ridges thus created. This removes the good topsoil from the furrow and the trees must be planted in less fertile subsoil.

Another disadvantage of the furrowing method is that the pronounced ridges and furrows interfere with driving or walking over the area. Disking with the Athens type of harrow overcomes these difficulties; the competition of the sod and lesser vegetation is eliminated while leaving in place the topsoil and maintaining the original level of the ground. An improvement in survival and in height growth of the planted trees was secured on disked in contrast to furrowed areas (Anonymous 1944).

Where plowing is impossible, such work of site preparation has to be done by scalping the undesired vegetation by hand labor from spots 1 to 2 feet square, spaced at the intervals at which trees will be planted. Plowing is much cheaper and prepares the site better. Shirley (1941, pp. 28-31) describes and shows illustrations of plows and bulldozer equipment for thinning the overstory, removing the undergrowth, and exposing mineral soil in planting-site preparation under Lake States conditions on aspen-covered lands.

Areas solidly covered with heavy, dense brush present a difficult and expensive planting problem. It is hard to plant the trees among the dense brush, and survival is low because of the intense competition. Removal of such undergrowth by hand labor is too expensive. Uprooting by machinery is usually attempted only on parallel strips 6 to 8 feet wide running through the brush area. The strips may be cleared with a powerful tractor that either pulls a heavy V-shaped plow or drag or pushes a V-shaped blade with a grader-type cutting edge. The cutting edge should penetrate only a little below the surface of the ground, as otherwise the root crowns of the brush would not be so effectively broken up and too much of the good topsoil would be pushed off the cleared strip. Such equipment has been found successful under the difficult conditions encountered in the brush fields of the California mountains (Abell 1938). The planting is done on the strips.

Where a dense grass or weed growth exists, burning over the area broadcast is a cheap and effective method to reduce the cost of planting slightly and to destroy, or possibly drive out, part of the rodent population which might later injure the planted trees. In some places the danger of increasing erosion makes the burning over of the planting area inadvisable. The effect of forest fires or the broadcast burning of slash on driving small rodents from the area burned over is as yet not thoroughly known. Probably rodents cannot be elimi-

nated in this way, if at all, for more than a short time. The succulent vegetation which develops after fire may furnish more food and attract such animals as rabbits.

Rodents are such a serious source of injury in many plantations that methods of destroying them or reducing their damage should be seriously considered. Practical methods are still in the experimental stage. What was said on page 56 concerning poisoning of rodents prior to direct seeding applies also to areas on which planting is to be undertaken.

The necessity of action to control various animals destructive to young planted trees has been recognized in the Douglas-fir region. Suggested means (Munger 1942) for control include: coating the tops of planting stock, while in the nursery just before the stock is dug for shipment, with a repellent or poisonous compound; poisoning the planting area to reduce population of such animals as rabbits and mountain beaver; encouraging the hunting of deer; and discouraging the hunting and trapping of such animals as coyotes and cats that prey on rodents.

The snowshoe hare is a dangerous enemy to young forest plantations in the Lake States. As practical means of combating this animal in plantations Shirley (1941, pp. 26-27), suggests planting in years when it is in the low portion of its population cycle; for large planting areas he advocates snaring, organized shooting, and driving. He considers snaring the cheapest method of eliminating hares. Where the most effective protection can be afforded, fencing with poultry netting, 4 to 5 feet high, is advised. The cost is estimated as $400 to $500 per mile.

Grazing by domestic animals, particularly goats, for a few seasons before planting may often result in reducing the vegetative cover on an area so that the labor of planting is lessened and higher survival of the planted trees is secured.

The methods of setting the plants in their permanent location are varied. All methods, though varying widely in tools used and in details of operation, are designed to set the plants in such a way as to ensure their survival under the local environmental conditions and at the same time to keep the cost of the operation at a reasonably low figure.

Trees should be planted ordinarily at the same depth at which they previously stood with the roots spread out in as natural a manner as possible. Where the roots are longer than can be conveniently planted, the lower portions may be pruned. Throughout the planting operation the roots should receive protection so as never to become

dry. The best and freshest soil available should be placed next to the roots. Soil (not litter) should be pressed tightly around the roots to avoid leaving any air spaces. The roots are usually planted in a vertical plane, but such a position is not necessary. In fact some authorities advocate, particularly for seedling stock, setting the roots in an oblique plane (for example, at approximately a 45° angle with the ground surface) rather than vertically (Münch 1932). The claimed advantages of the oblique planting are, first, the more certain closure of all air spaces, since gravity assists in bringing soil against all the roots, and second, a greater certainty of proper rooting. On the other hand if oblique planting results in appreciably decreasing the depth to which roots are set, as compared to vertical setting, the loss in periods of drought may be greater. Although the root system of trees obliquely planted at first may be lopsided, this condition soon disappears and the plant ordinarily becomes erect above ground within a year. There is some evidence that jack pine in the Lake States develops better when planted on a slant.

When possible, planting the trees in the shade of stumps, logs, stones, or brush piles may protect against the sun and increase survival. Spacing should be varied sufficiently to take advantage of such shelter.

The tree, when planting is completed, should be tightly held by the soil, as tested by pulling gently on the top with thumb and forefinger.

Planting of balled trees, so common in ornamental planting, is too expensive for forest planting. There are exceptions to this rule as, for example, the planting of small trees in briquettes (Heiberg 1934), pots, or flats, but these methods have not as yet been found necessary or economical in this country. Planting naked-rooted trees is the custom in present-day forest planting.

Toumey and Korstian (1942) divide planting methods for naked-rooted plants into (*a*) compression methods, in which the soil is compressed to make a hole for the plant, the plant is placed in the hole and the soil is finally compressed against the tree, and (*b*) dug-hole methods in which holes are dug and the dirt piled beside the holes to be used in planting the tree. This is a convenient division which will be followed in the present discussion.

In compression methods tools of slightly wedge-shaped form usually are employed. The tool is driven into the ground, forcing the soil sidewise, and then withdrawn. The tree is placed in the hole, its roots being shaken down into the slit. While the planter holds the tree, the planting tool is driven into the soil a few inches from the plant, forcing the soil tight against the tree. This last hole

is closed by a thrust of the planter's foot as he goes forward. The compression method of planting is a quick and consequently a cheap method, often costing less than half as much as the hole-digging methods.

The dangers in compression planting are, first, that the hole will not be tightly closed, leaving air spaces around the roots; second, that the competition of vegetation left close around the planted tree will kill it; and, third, that the roots will be caught on the sides of the narrow hole and not be placed at proper depth. The first disadvantage is negligible on sandy soils, and the second is unimportant on sites where the vegetation is sparse. Furthermore, the injurious effect of competing vegetation can be lessened by site preparation, removing the competing grasses or other plants prior to planting. The third disadvantage, namely possible failure to obtain proper position of the roots, can be overcome only by careful work on the part of the planter. Young stock with a relatively small root system is better adapted for planting by compression methods than the larger, stiffer-rooted transplant stock. Compression methods are not suited to heavy or stony soils, or those containing many interlacing roots.

Various tools are employed in planting by the compression method, and the detailed technique of conducting the operation varies with the tool. The planting bars and Choctawatchee planting tool developed for setting southern yellow pines (Wakeley 1935) illustrate tools well adapted for use in sandy soils. The bars are about 45 inches long and have a slightly wedge-shaped steel blade about 10 inches long and 3½ inches wide, with an iron step at the top of the blade. The blade is driven in full length, moved slightly to free itself, and then withdrawn. Into the slit thus made, which is less than 2 inches across at the top, a tree is inserted and shaken to arrange the roots properly. A second stroke of the bar, a few inches behind the first stroke, closes the hole at the bottom and partly at the top. With his heel the planter finishes closing the slit at the top. Either one man may work alone with these bars or the crew unit may be 2 men. Two men should plant from 1600 to 2400 trees per 8-hour day.

The Choctawatchee tool is a short planting bar to be used on brushy sites and light soils where a longer tool is awkward and one man works alone.

Where cuttings or seedlings with a single stiff root are to be planted a planting tool made from a round bar of uniform diameter is cheap and efficient, particularly in heavy soils. For example

Bull and Muntz (1943) recommend such a bar, either ¼ or ½ inch in diameter, for planting cuttings and seedlings of cottonwood.

Where the planting site can be plowed, a trencher-type plow may be used to open up a continuous slit. Men follow the machine and set plants in this slit at desired intervals In connection with the trenching method just mentioned, furrows to prepare the site may be plowed ahead of the trencher and the trenching done in the bottom of the furrow. Instead of trenching after furrowing, the planting may be done in the furrow with any of the tools used in the compression methods. Planting in furrows has the effect of getting the tree roots deeper into the soil than they would otherwise be, as well as of lessening competition. Hence furrowing may be advisable on sites where there is danger of the upper soil layers drying out thoroughly, or where severe competition is feared. Disadvantages of planting in furrows are that the plants may be covered up by soil silting in from the sides of the furrow and that the trees are set in relatively infertile subsoil instead of in fertile topsoil.

Various machines for planting trees have been developed. The New York State Conservation Department first used such a machine in 1930 (Anonymous 1930), and a machine of similar type has been employed by the Prairie States Forestry Project (Anonymous 1942). The latter with a crew of 3 men performs the work of about 16 men with hand tools. These machines open a narrow trench by a plowshare, set the plants in the trench, and fill in and firm the soil around the plants. One or more men riding on the machine feed the plants into the machine. The planting is done much cheaper than by hand. Skillful operators and the right conditions of site are required for successful machine planting. The method is not suited for rocky soils, wet soils, or steep slopes.

On stony soils and those of heavy type, which tend to compact on compression, the grub hoe rather than the planting bar is the tool most frequently employed in planting. The cheapest way to use this tool is to strike it into the ground, then pull straight up and, as sometimes done, sideways on the handle, thereby opening a slit at the end or side of the grub hoe. The plant is inserted in this slit, its roots brought into proper position, and the raised soil dropped back into place as the grub hoe is removed. The soil is firmed around the tree by the planter's feet. Competition from other plants can be lessened by previous site preparation or by removing with the grub hoe, at the time of planting, the sod and other small plants for a foot or more around the planted tree.

A light grub hoe with a short handle 16 to 18 inches long has been

used in some parts of the West. The tool is released from the hand just before the blade strikes the ground, thus reducing the strain on the wrist and preventing bruised knuckles. The tool should be buried in the ground up to the eye and then the handle should be lifted up and pulled slightly toward the planter. A narrow, square-bottomed hole is thus opened. The tree is inserted in the hole, the grub hoe removed, and the soil packed against the tree with the blade of the grub hoe. Both these grub-hoe methods are cheap, quick methods of planting, in type halfway between compression and dug-hole methods, and are sometimes known as the modified slit method or the grub hoe-slit method (Kummel, Rindt, and Munger 1944, pp. 114-115).

Dug-hole planting methods are needed on the more difficult sites. Here for one reason or another the cheaper compression methods fail to obtain survival adequate for satisfactory plantations. In this method holes are dug deep enough to accommodate, without doubling up, the root system of the stock being planted. The method thus is adapted for any size of tree. The mineral soil should be piled beside the hole separate from leaves, sod, and other debris to facilitate planting and to encourage the use of clean soil close to the roots. The trees should be planted promptly after the holes are dug before the exposed soil has opportunity to dry out. Planting is done by hand.

The plants may either be placed against the side of the hole or be set in the middle of the hole. If the plants are placed against the side of the hole, it is easier to ensure that the tree is set at the right level and that the roots are spread out vertically. The disadvantage of side planting is that the tree may be brought into somewhat closer contact with adjoining vegetation. This objection can be overcome if scalping has been done previously, or by removing when planting such vegetation from a 12- to 24-inch square, and then digging the hole in the center of this cleared square. Perfect planting in the center of the dug hole may give a better horizontal distribution of the roots but if not well done is likely to result in the root system's being compressed vertically. In either center or side hole planting the soil should be packed tightly close to the roots but left loose for the last inch on the surface to conserve soil moisture better. The best method of firming soil about the roots is to put only a small quantity of soil against them and tamp it, repeating the operation if necessary. The remainder of the soil can be rapidly filled in around the tree. The grub hoe is the tool ordinarily employed in dug-hole planting. Usually two men work together, one digging the holes and the other planting the trees. The whole operation can, however, be carried on effectively by a single man.

A variation of dug-hole planting, known as the wedge method, is designed to give a wider spread distribution of the roots. In compression methods the roots are all in one plane. This has been considered a dangerous practice, at least on heavy soils which compact easily and on sites with difficult climatic conditions, although evidence to prove this point generally as it applies to plantations in this country is not yet available. The dug-hole method gives a more varied distribution of the roots and ordinarily better survival than compression methods, but even here careless work especially in side hole planting may result in the roots being in one plane. In wedge planting a wedge of soil with its broad base in the bottom of the hole is constructed and the tree roots are distributed on the two sides of this soil wedge. In theory a cone of soil would be better than a wedge, since the roots could then be distributed in all directions and a better-balanced root system would be developed. As a practical matter it is easier and cheaper to make a wedge of soil, rather than a cone, in the bottom of the hole. This can be done with a tiling spade or with a special tool similar to a grub hoe with which efficiently to dig holes leaving wedges at the bottom. Even with this tool, digging the holes will be more expensive than usual dug-hole planting as the digger must work from two sides of the hole. Wedge planting is about twice as expensive as slit planting.

The cost of dug-hole planting will be influenced by the width of the hole, which is sometimes only equal to the width of the grub-hoe blade and rarely more than twice that width. Obviously more labor is expended in digging the wider hole. Region 2 of the United States Forest Service terms the method using a hole of double grub-hoe width "deep-hole planting"; using a hole of single grub hoe width "simple-hole planting."

As regards cost of planting the methods may be arranged as follows with the least expensive in first cost placed at the top of the list. Rarely are more than two methods used on a commercial scale in a given locality under a given set of conditions, and often only one method is so employed.

Machine planting.
Trencher slit.
Slit using planting bars.
Modified slit.
Simple hole.
Deep hole.
Wedge.

For the success of every planting job, it is essential that the trees

sent from the nursery be taken care of properly from the time they are received until they are planted. Often the trees can be heeled in on the planting site and taken out as needed for immediate planting. Heeling-in consists of digging a trench with a smooth, slanting side as deep as the roots of the planting stock are·long. The trees with the roots down are packed in this trench in a relatively thin layer and covered with tightly packed soil up to the root collar. If protected from sun and wind and if the weather is cool, trees can remain heeled in for one or two weeks without injury. A place with moist to wet soil should be selected for heeling in, particularly if the trees will remain for several days.

Planting stock in storage is exposed not only to the danger of drying out but also to that of becoming heated and molding, if the tops are not kept cool and if they do not have good ventilation. Furthermore, the plants may start to grow. If the soil and weather conditions are not favorable for holding stock heeled in for a long period, and yet it is necessary to hold them, special cold storage should be provided. This may consist of an ordinary cellar with arrangements for keeping the temperature down to at least 40° F. Region 9 of the United States Forest Service (Anonymous 1936) advises the use of simply constructed racks in which the trees may be packed, with cakes of ice on the upper shelf of each rack.

The trees are ordinarily carried by the planting crews in pails, baskets, bags, trays, or other specially designed containers. A container large enough to carry the plants laid on their sides enables the planter to take out individual plants more easily than if the plants stand on end. The essential point to control, while the trees are in possession of the planting crew, is that the roots be kept moist and not allowed to dry out in the sun and wind. Moss, a puddle of wet mud, or other material for keeping the roots moist is often placed in the container.

Clearcutting with artificial reproduction has the various advantages and disadvantages of clearcutting in general as discussed on pages 92 to 95 but has in addition one decisive advantage. Many stands today are composed of species less desirable than one or several species which might be more profitably grown on the site. Clearcutting, followed by artificial reproduction of the desired species, is the most effective method and usually the only way available for changing to the better composition.

Application of Clearcutting with Artificial Reproduction. It is estimated that at least 3 million acres of land in this country have been planted with forest trees by public and private agencies. Nearly

all this planting was done on old burns and other non-forested lands. Undoubtedly many of these areas had been cut clear in the past, but only for exploitation of the mature timber, and not as foresters apply the clearcutting method with consideration for obtaining a new crop. The extent of the bare areas still remaining is so great that a large proportion of all artificial reproduction undertaken over the country during the next few decades will be in their reforestation.

However, the method of clearcutting with artificial reproduction is already being applied on a limited scale under conditions which make it, in contrast to other reproduction methods, practical for attainment of specific management objectives. A few examples will serve to illustrate the point.

On the Yale Forest near Keene, N. H., areas stocked with stands of quite open-grown, relatively low-quality, but merchantable eastern white pine are clearcut and planted two seasons later with white pine. The delay in planting is necessary to avoid serious injury by pales weevil. Partial cuttings and attainment of natural regeneration of white pine are impractical in these stands because of the limited value of the trees for future growth and the certainty that hardwoods, undesirable to grow on the site and already abundantly present as reproduction owing to past mismanagement, would take possession if partial cuttings were made. If current market conditions are favorable, the slash may be broken up by cutting tops into cordwood sufficiently to allow planting without further slash disposal. If cordwood cannot be sold an expenditure up to $10 per acre for slash disposal may be necessary. Either 2–0 seedlings from open-grown nursery beds or 2–1 transplants are set out at the rate of 1000 per acre. The transplant stock costs about $7 per acre and the planting about $7. Keeping the young pines from suppression by the hardwood requires 3 to 5 cleanings during the 10 years after planting at an average expenditure of time for each cleaning of half a man-day per acre. At $4 per day this may amount to $10. The cost of establishing a pure stand of white pine, with a lower story of hardwoods acting as trainers, is therefore $24 to $34 per acre. The management objective of this forest is the production of white pine which it is believed will prove profitable even with such expenditures for establishing the crop.

Mature (over 60 years), fully stocked evenaged stands of good-quality eastern white pine *previously unmanaged* in New England are often best harvested and reproduced by clearcutting and planting. The lack of previous cutting during the life of the stand has often reduced the live crown to such a small proportion of the total

height as to make partial cutting unwise because of probable windthrow and breakage following such cutting. Planting costs would be the same ($14 per acre) as in the previous example, but only 2 cleanings should be necessary at a cost of $4 per acre. Total cost of establishing the new crop is thus $18 per acre.

In the western white pine region of northern Idaho one method of reproducing a certain type of white pine stands, with stumpage values of about $300 per acre (specifically mature, evenaged stands, composed predominantly of white pine trees containing high-quality timber), is by clearcutting and replanting the area (Davis 1942). Although such stands can be reproduced by this method, clearcutting with natural regeneration may also be successfully used and will often be preferable. Where artificial reproduction is employed the merchantable timber is clear cut, the unmerchantable trees, mainly of inferior species, are felled, and the area is broadcast burned and then planted with western white pine. The cost of artificial reproduction, as estimated by Davis (1942, p. 19), is $39 per acre, of which $15 is for the planting, $16 for felling the residual stand, and $8 for the broadcast burning operation. Costs, if methods of natural regeneration are followed, are estimated as $66.80 per acre under the scattered-seed-tree method, and $56.80 per acre if clearcutting in strips leaving alternate seed-tree strips is employed.

It should be emphasized that for both eastern and western white pine clearcutting with artificial reproduction is the proper method only under certain specific stand conditions. Both species, if taken under management before middle age is past, are because of their silvical habits better adapted to natural regeneration under a shelterwood than to clearcutting.

The Oregon Forest Conservation Act requires restocking of areas from which live timber is cut for commercial use. Most operations west of the Cascades in the Douglas-fir forests of Oregon still practice clearcutting. Usually natural regeneration can be relied upon to restock these cutover areas, but the law allows the use of artificial reproduction for restocking, if the operator desires, provided that it is done under a plan approved by the state forester. The Weyerhaeuser Timber Company (Anonymous 1934) estimated the cost of artificial restocking of cutover lands in the Douglas-fir region at $5.00 per acre for planting, with a spacing of 10 by 10 or 12 by 12 feet; direct seeding was considered more expensive. The cost of planting was considered to exceed the expense required to obtain natural regneration in many cases.

Kirkland and Brandstrom (1936, pp. 32-33) consider that 15-

by 15- or 20- by 20-foot spacing will give adequate stocking at a cost of $2 to $4 per acre, since natural regeneration of western hemlock would supplement the planted stand. They advise planting Sitka spruce, Douglas-fir, and Port Orford white-cedar.

Work along this line is intensive and is being undertaken today principally on small tracts in the North Atlantic states or on publicly owned lands, but is likely to find increasing use in many parts of the country. It is an expensive operation since usually the artificially established trees must be protected against competition from the species present in the stand just cut. The problem has been solved sometimes in the mixed forests of the tropics, containing many species but only a few of merchantable value, by clearcutting the existing stand, using the land for a few years to produce agricultural crops, and meanwhile planting the desired species of forest trees among the agricultural crops. The agricultural crops lessen the final expense of establishing the new forest crop. The work is usually done on a contract basis by agricultural workers. It has been suggested as a possible method of bringing relatively unproductive portions of the mixed hardwood forests of the Mississippi River Delta into productive stands of the more desirable hardwoods.

Shirley (1941, pp. 31-33) recommends the planting of poor-quality aspen lands in the Lake States to conifers, thus changing a forest type of low productive value for one capable of producing excellent yields. He estimates the cost of such a change at $30 per acre, made up of the following items: preparation of site $5, snaring and shooting rabbits $2, planting stock $6, planting $4, releasing the planted trees by 4 to 5 operations $13. Apparently the returns to be expected from planting jack, red, and white pines and white spruce will range from $35 to $168 per acre at 65 to 120 years, depending on treatment. Whether the change in type will prove to be an interest-bearing investment for the first rotation is open to question. Shirley considers that the social and economic benefits resulting from productive lands justify the expenditures necessary to restore conifers to lands in poor-quality aspen.

Troup's (1928, p. 27) opinion as regards the use of clearcutting with artificial reproduction is of interest: "The predicted world shortage of timber, particularly of soft woods, is a factor which is likely to raise the importance of this system to a level never attained before, since measures necessary to meet this shortage must include the formation of extensive plantations of conifers on areas where they have not existed previously or where they have been depleted by wasteful methods of working. Everything therefore points to the

increasing importance of the clearcutting system in spite of any disadvantages it may possess."

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CHAPTER IV

CLEARCUTTING WITH NATURAL REPRODUCTION

Discussion concerning *definition* of the clearcutting method and *form of forest produced* will be found at the beginning of Chapter III.

Details of the Method. The stand is cut clear and reproduction springs up naturally on the clear area. This reproduction, to secure best results, should start immediately but frequently requires several years. The seed from which the new stand originates comes from three sources:

1. Trees standing outside, usually adjacent to, the area cleared. The seed is disseminated by wind over the cleared area, most thickly

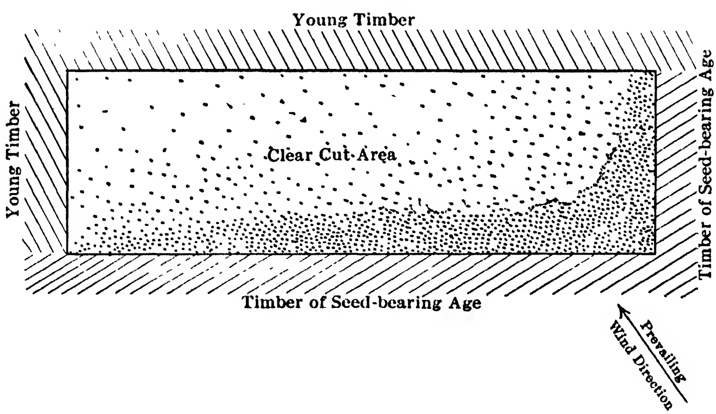

Fig. 2.

Clearcutting the whole stand, with reproduction secured by seed disseminated from seed trees located outside the cut stand. The density of the reproduction five years after the cutting is indicated by the dots.

close to the parent trees on the borders of the clearing, and in decreasing amount toward the center. Reproduction arising from such seeding is likely to be too dense around the edges and too sparse or lacking altogether in the middle. (See Fig. 2.) Loblolly pine, as well as many other American species, reproduces prolifically from seed blown onto the clearcut area from adjoining seed-bearing trees.

2. Seed stored in the forest floor. Occasionally, with a species like

western white pine whose seeds normally are slow in germinating, quantities of seed may accumulate in the forest floor, retaining vitality for one or more years and germinating when subjected to the changed conditions following a clearcutting. Reproduction thus secured may be relatively uniform in its distribution over large areas.

Western white pine appears to be the only North American tree species which possesses the ability to establish satisfactory regeneration from seed stored in the forest floor for more than one winter. Even with this species success is uncertain. Haig, Davis, and Weidman (1941), who investigated this subject, consider that on not over 25 per cent of the numerous cutover areas examined was satisfactory regeneration secured from seed stored in the forest floor. Furthermore their estimate included seed of the current crop as well as that stored longer than over winter. Less than one third of western white pine seed remains viable longer than one season, and practically all that will germinate has done so by the end of the second season.

3. Seed stored on the trees removed in the clearcutting, or recently fallen from these trees. Certain species, lodgepole and jack pines, for example, retain portions of several seed crops for a number of years. After cutting (also after fires) such seed may be released from the cones and germinate. With most species the seed stored on the trees is only the current seed crop and is disseminated shortly after ripening. This seed may be still on the trees or recently fallen to the ground. A uniform and complete reproduction frequently will follow where this source of seed is available on the cleared area.

Successful natural reproduction after a clearcutting depends, first, on an abundant seed supply distributed over the entire area, and second, upon the existence of conditions favorable to the germination of the seed and development of the young seedlings. The method involves a sudden and complete exposure of the ground to sun and wind. In order to secure a new crop, the species being reproduced must be capable of establishing itself under these difficult conditions. Since clearcutting subjects the seed and the small seedlings to greater exposure than other reproduction methods, it follows that these two requirements for success of the method must be met with precision before natural reproduction will appear.

In providing for an abundant seed supply the sources from which seed may be expected and the probable amount must be considered, as well as the natural enemies, especially rodents, which may destroy the seed. In artificial seeding the distribution of poison systematically over the area to be reproduced in order to kill the rodents has been used. Such methods, applied just before a seed year in

stands about to be reproduced naturally, might be effective in increasing the seed supply available for germination. No instances are known where this has been done, the expense being large and success uncertain. However, Krauch (1945) has recommended such action for Douglas-fir in the Southwest. Krauch considers control of rodents, particularly mice, of great importance in securing satisfactory natural regeneration of Douglas-fir in the Southwest, where climatic conditions render natural regeneration difficult, rodents are abundant, and the seed supply is relatively scanty. The mice both eat the seeds and nip off the young seedlings soon after they appear. He advises poisoning of cutover areas in good seed years.

Where seed from surrounding trees is the only source, the clearing must be sufficiently small (usually long and narrow) to allow for adequate dissemination to all points. Safe widths for clearings to be stocked by wind-disseminated seed are likely to range, depending on species, from one to five times the height of the adjacent timber from which seed will be obtained. Direction of the wind at the time of seed dispersal should be known and the clearing be so located that its long axis is at right angles to the wind direction. This point has value only in regions where wind directions are relatively constant at time of seed dispersal, and furthermore other considerations such as topography and direction with respect to the sun are often more influential than seed dispersal in determining the exact location of the cutting area.

Unless the cleared area can be made very narrow a heavy-seeded species, depending principally upon gravity for dissemination, will not furnish sufficient seed from trees outside the clearing. When seed in the forest floor or on the trees which are to be cut is available the weight of the seed becomes less important.

After an adequate dispersal of seed over the clearing is provided for, favorable conditions for germination and early growth of seedlings of the desired species must be established and maintained for a few years. Moisture conditions on the clearing can be partially controlled by varying the width of the area cut clear. With a narrow strip, the adjacent timber affords protection against sun and wind. Proper regulation of moisture conditions may make the difference between success and failure of the reproduction. The establishment and maintenance of favorable conditions for germination and early growth of seedlings often necessitate undertaking special work for this specific purpose as described in the following section. The silvical habits of the species together with the condition of the seedbed will indicate the kind and amount of work needed.

Preparation of the Cutover Area Preliminary to the Establishment of Reproduction. After the mature timber is harvested, the cutover area, whether it is cut clear or only partially cut, is likely to require treatment before conditions suitable for the germination of seed and for the early survival of seedlings are created. This preparation usually is wanted just before reproduction is to be established. If the treatment is omitted reproduction may be a complete or partial failure.

In principle, preparation of the cutover area preliminary to the establishment of reproduction applies almost irrespective of the reproduction method under which the forest is being managed. Details of application and the relative importance of different types of treatment vary for the several reproduction methods. But greater variations in the kind of preparatory work required occur between the tree species than between reproduction methods. Hence in application the requirements of the species which is being reproduced are of paramount importance in determining the kind and extent of the preparatory work. With some species little if any preliminary preparation of the cutover area will be needed, whereas with others intensive preparation, carefully timed to take advantage of the seed supply, will prove essential for the establishment of reproduction.

The subject is taken up here under the clearcutting method for convenience, as it is first reached at this point. What is said applies also to preparation of the cutover areas under the other reproduction methods and should be referred to when the subject is considered in applying any reproduction method.

A soil bare of live vegetation with the upper layers in reasonably loose condition and not lacking in moisture and nourishing elements represents the ideal for the start of natural regeneration. A completely satisfactory condition of this sort cannot be obtained in most places without prohibitive cost, but whatever work is done should be directed toward approaching this ideal.

Preparation of the cutover area preliminary to the establishment of reproduction may be classified into the following four types of work:

1. Disposal of the slash or debris left by the logging operation, principally the tops and limbs of felled trees.

2. Treatment of live vegetation which may compete with the reproduction. The live vegetation is composed of all classes of plants ranging from small annuals up to trees.

3. Treatment of the dead organic material making up the forest floor.

4. Treatment of the soil.

All these matters are considered here from the standpoint of their effect upon the establishment of reproduction. It is recognized that for some items, particularly disposal of slash, other reasons, as for example protection against fire, may influence the amount and kind of the work undertaken. Each of the four types of preparatory work will be discussed separately.

Disposal of Slash. Logging debris on the whole has a harmful influence on the establishment of reproduction. The harmful effect is due principally to the mechanical effect of the debris in densely covering parts of the area, either burying the reproduction already on the area or preventing the start of any new trees. Obviously it increases with the thickness of the layer of debris and with the percentage of the area that is occupied by heavy accumulations of slash. In light cuttings the areas of dense slash may be so small and so well scattered as to offer no mechanical impediment to a satisfactory restocking.

Even where slash covers the ground so lightly as not to bury existing reproduction or prevent the development of new plants provided that the seed germinates, it may still prove detrimental to reproduction by changing seedbed conditions for the worse. Either the additional shade produced by the light cover of slash or the extra cover of leaves falling from the slash may prove harmful to the germination of seed or the early survival of the seedlings. On the other hand the reverse may be true, the light cover of slash creating just the seedbed conditions desired. Possibly the protection of the slash may save the trees from injury by grazing animals, or conversely it may protect competing vegetation even better and thus indirectly be of injury to reproduction.

A special situation exists with respect to the slash from species like jack pine which retain nearly all the seed in unopened cones either until after cutting occurs or until fire kills the standing trees. In obtaining reproduction of jack pine after cutting an essential step consists in scattering the slash over the clearcut area in such fashion that the cone-bearing branches of the slash are left lying on patches of exposed mineral soil (Zehngraff 1943).

Definite knowledge of just how the slash left on any given area is going to affect reproduction of the particular species desired on that area is evidently a requisite before a decision can be made about how the slash should be treated. Methods of slash disposal are discussed in Chapter XV, which should be consulted for further details.

Treatment of Live Vegetation Which May Compete with the Reproduction. Frequently trees of inferior species and defective in-

dividuals of valuable species are left on cutover areas after the reproduction cutting is finished. This happens most frequently on clearcut areas or after partial cuttings in regions where it is impossible to find a market for defective trees and the less valuable species. Such trees, given greater growing space by the cutting, are likely to develop spreading crowns and either prevent reproduction under their crowns entirely or at least hamper growth seriously. If these undesirable trees could be sold even for enough to cover only the costs of removal it should be done. If this has been tried and found impracticable, it becomes a question of felling the trees and perhaps piling and burning the tops, girdling the trees, poisoning them, or killing them by fire. The details of girdling and poisoning trees are discussed on pages 209 to 212. On clearcut areas fire, either run broadcast over the area or set in piles of slash, and intentionally allowed to accumulate under the trees to be destroyed, will kill them cheaply, but the dead trees remain as snags and increase the fire hazard. Where this is an important drawback or where reproduction will be adversely affected by a burned-over seedbed, fire should not be employed to kill undesirable trees. Both girdling and poisoning create dead snags which are unsightly, and conifers so treated may become fire hazards. These methods are cheaper than felling the trees and disposing of the brush.

Lesser vegetation consisting of grasses, herbaceous plants, and woody shrubs frequently offers serious interference with the establishment of reproduction. If seeds germinate under the cover of lesser vegetation, the seedlings have difficulty in obtaining sufficient moisture in competition with the already established plants. Furthermore many woody shrubs have such dense foliage and are so tall as to reduce the sunlight below the amount needed for healthy development of tree seedlings.

An effective way of reducing the competition of grasses and herbaceous plants is to turn domestic stock into the cutover area. Closely cropped forage plants offer relatively little competition with reproduction. This treatment is applicable only if the tree species being reproduced are not palatable to the stock, which in general is true for conifers as contrasted with broadleaf species. Woody shrubs can occasionally though less commonly be kept down by grazing. Their destruction must be accomplished by cutting, poisoning, uprooting (preferably by plows or harrows), or burning. The least expensive way is burning over the area. Most of the shrubs will sprout, but quite likely for a year or two there will be small openings between sprout clumps and hence more room for reproduction to

develop. Later the reproduction may need to be released from overtopping shrub clumps. If the seedbed will be affected favorably by fire, then burning over the area is the best way to treat underbrush.

Tearing up strips through the underbrush 10 to 20 feet apart with a tractor-drawn plow or heavy disk-type harrow should be effective under some conditions in opening up dense underbrush sufficiently to admit reproduction. Such equipment is used for constructing firebreaks and preparing planting sites. The method has the advantage of exposing and working up the soil into a good seedbed at the same time that the underbrush is eradicated. Cutting by hand is too expensive.

The use of poisoning to kill underbrush is still in the experimental stage.

Treatment of the Dead Organic Material Making up the Forest Floor. After providing for an adequate seed supply, the next step of primary importance is the preparation of a seedbed favorable for the germination of the seed and early survival of the seedlings, which usually resolves into treatment of the dead organic material on the ground. The fallen leaves, twigs, and other plant remains in various stages of decomposition often form layers several inches deep overlying the mineral soil. When kept moist this material makes an excellent germinating bed for the seed of many species. The difficulty is that only under special circumstances does it remain moist during the critical periods of seed germination and early life of the seedling. The surface layers of litter usually become dry. Most of the seed lies in these surface layers and is likely to be kept too dry for germination, or if the seed germinates the young plant is dried out and dies before its roots can penetrate to the mineral soil. The worst conditions are when the litter is very thick or a deep layer of unincorporated humus has developed. There may be species which prefer a litter- or humus-covered seedbed to one of exposed mineral soil, but most species reproduce more vigorously where only a small amount of dead organic matter covers or is mixed in with the mineral soil.

Treatment may consist of mixing the litter and unincorporated humus up with the soil, burning off the dead organic material, or removing it in some other way. The exposure of the area brought about by the cutting will hasten decomposition, but frequently this will progress too slowly to favor prompt regeneration.

The logging operation, if done when the ground is bare of snow, may result in mixing the forest floor with the mineral soil over enough of the cutover area to ensure satisfactory restocking. Other

methods of accomplishing the same purpose have been employed. Shirley (1933) sucessfully prepared the seedbed in a red pine forest by means of a disk harrow. He advises disking the area in strips at a cost of $1.00 to $1.25 per acre. In European practice (Hilf 1930) varied equipment, consisting chiefly of plows, harrows, and drags, has been developed for preparing the seedbed. Sometimes, instead of making strips, small, scattered seed spots are worked. If the operation is performed with a hand tool this method may effect a saving over the strips, though on the whole the machine-worked strips will be cheaper. If the forests are interspersed with agricultural areas, it is sometimes possible to get the litter removed by farmers without cost or even at a small profit.

Burning over the area is an excellent way to create the right seedbed for certain species. Cope (1924) used the method successfully in reproducing loblolly pine, the fire serving the two purposes of burning off the litter and killing underbrush and undesirable tree species.

TABLE II

	Number of seedlings per acre		
	Jack Pine	Black Spruce	Paper Birch
Duff not disturbed	0	0	333
Duff torn up with mattocks	1,365	45	728
Duff removed	14,250	1,425	4,950

Not only does the fire assist the seed to come into direct contact with the mineral soil but also it may improve the chemical properties of the soil by decreasing the acidity, by the addition of wood ash, and by stimulating the production of available nitrogen. The physical properties of the soil are of course affected, sometimes beneficially, sometimes injuriously. With a mull type of humus layer a fire may be expected to injure soil conditions. Fortunately if a mull exists there is ordinarily no need for improving the seedbed by burning. Where the humus layer is of the mor type, fire improves the seedbed. Burning to assist reproduction must of course come before and not after the fall of the seed.

An experiment in the Lake States (Anonymous 1936) indicates what an important effect treatment of the forest floor may have upon the amount of subsequent reproduction. Three treatments were applied in a 70-year-old jack pine stand having a tough 2-inch layer of unincorporated humus (described as duff). Four months later the stand was clearcut and slash lopped and scattered. The treatments and number of seedlings present the first August after cutting are indicated in Table II.

The seed of longleaf pine is too large to work through a thick forest floor to mineral soil. To obtain satisfactory regeneration of longleaf pine such a cover must be removed. Burning over the area either just before seed fall or else one growing season in advance of seed fall increases the amount of longleaf pine reproduction. The latter time is likely to give better results as a slight cover is afforded the seeds, which may be effective in protecting many of them from being eaten by birds and rodents.

Treatment of the Soil. The emphasis so far in the treatment preparatory to reproduction has been on bringing the seed in contact with the soil. If live vegetation and unincorporated humus and the litter of dead material are removed it is questionable whether further work to loosen the soil is essential. Natural regeneration ordinarily should start on bare soil. Usually the methods of treatment already advised will be adequate without further effort. In some few places, especially where the soil has been exposed before the cutting, special treatment to improve soil conditions will be necessary. For example, in repeatedly burned-over forests there may be no vegetation or dead organic material on the ground. Here the soil is already bare but reproduction is unable to get established. The trouble is that the soil is too compact. Seed falling upon it lies exposed on the surface. If the seed germinates the root is dried out before it can penetrate the hard soil. Wherever exposed compacted soil occurs, breaking up of the surface with a machine or hand tool is beneficial. To cheapen the cost this may be done in strips or in small spots scattered over the area.

Arrangement of the Clearcut Areas. In both of the forms of the clearcutting method (with artificial or with natural reproduction) so far considered, the entire stand has been cut clear. One or more stands will make up the annual cut of the forest. The forest should contain enough stands to permit of one or more bei
In order to avoid too large clearings, for reason
or to be explained under "Advantages a
stands are kept relatively small, or at l
Stands cut in consecutive year
forest and arran
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tiguous

ordinary meaning the term clearcutting implies the removal of the whole stand at one time. If the individual stand or area of timber to be cut clear is large several years may be required to complete the operation.

The reasons for extending a clearcutting operation through more than one year arise not entirely from logging considerations as to

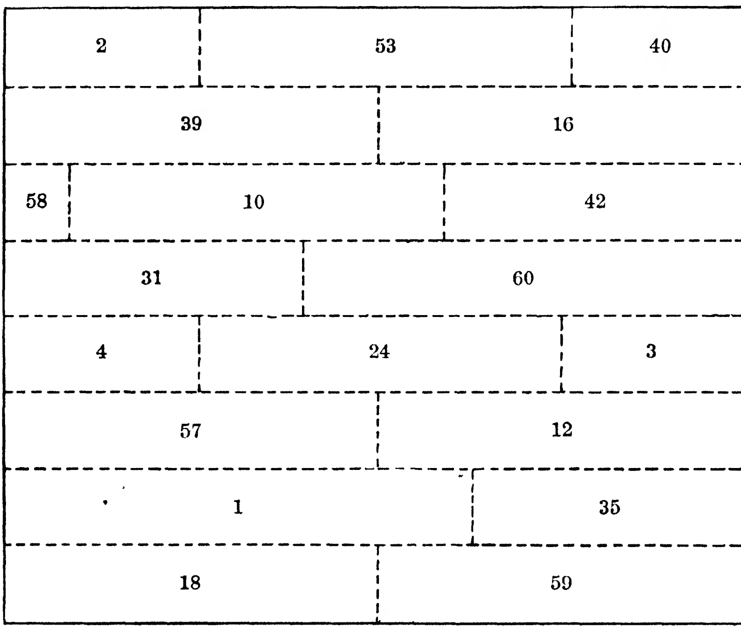

FIG. 3.

Theoretical arrangement of a portion of the stands in a forest managed on a
reproduced by clearcutting the whole stand. The numbers
of each stand. For example, the stand marked " 12 " was
is stocked with trees 12 years of age. The one marked
the present year.

although they may have weight.
of the species, par-
the area,
should

Clearcutting the whole stand.
Clearcutting in strips:
(*a*) Alternate strips.
(*b*) Progressive strips.

The first method has already been discussed; it remains to consider the strip methods.

Clearcutting in Strips. (*a*) *Alternate strips.* Under this arrangement the stand is divided into a series of strips as shown in Figures

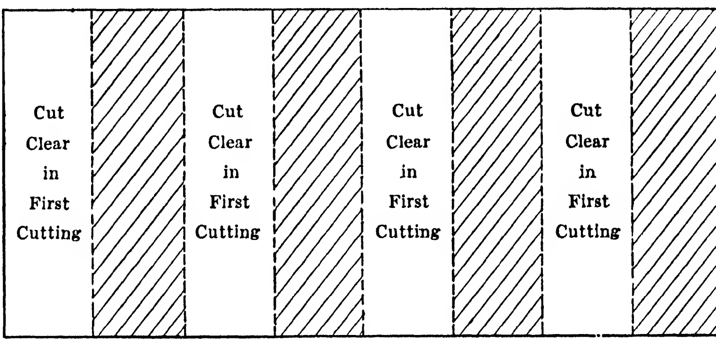

Fig. 4.

The arrangement of the strips in a stand to be reproduced by clearcutting in alternate strips.

4 and 5. The first strip is cut clear, the next left standing, the third cut, and so on throughout the stand. A few years later, after reproduction is established, the timber on the uncut strips is removed.

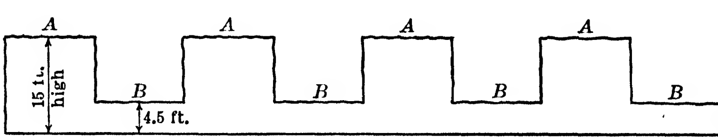

Fig. 5.

The same stand as shown in Figure 4, but 10 years after the clearcutting of the strips marked *A* and 5 years after the clearcutting and reproduction by planting of the strips marked *B*. Although there are now differences in height and age between the reproduction of the two sets of strips yet these differences are too small to cause the stand as a whole to lose its evenaged form. The difference in height will decrease as the stand grows older.

The two cuttings must occur close enough together in point of time so that the resultant stand remains evenaged. From 1 to 20 years under ordinary circumstances is the possible range of interval between

the two cuttings. Three to ten years may be considered average.

Reproduction may be secured either artificially or naturally. In general, the whole stand is cut clear when artificial reproduction is to be employed, because the need for providing and distributing an adequate supply of seed and for creating ideal seedbed conditions becomes of importance chiefly where dependence is placed upon natural reproduction.

The timber on the uncut strips furnishes a portion or all of the seed for stocking the cut strips, to some extent favorably affects site conditions on cut strips, and affords partial protection to the seedlings that start. To perform these functions to best advantage the uncut strips must be relatively close together and at right angles to the wind direction at seed-dispersal time. Seed may be scattered from the trees on an uncut strip in two directions over the two adjoining cutover areas.

When the strips of timber left at the time of the first cut are removed, natural reproduction on these areas cannot be secured in the same way as on the strips first cut. No belts of timber are left to furnish seed. Either the seed must come from the trees that are cut or else artificial reproduction must be resorted to. If a seed year can be selected as the time for making the second cutting successful reproduction may be secured. In many cases the cutting cannot be delayed until a good seed year. Under such circumstances, in order to secure natural reproduction, some other method than clearcutting may be adopted to reproduce the strips left standing at the first cutting. The seed tree or the shelterwood methods are commonly employed (Chapters V and VI), either of which necessitates two or more cuttings to remove the timber and hence lengthens the total period of regeneration.

Reproduction may sometimes be hastened and made more certain by thinning the uncut strips when the first strips are clearcut. This treatment has been found successful for loblolly pine.

Where the uncut strip is not wider than the height of the timber, the side light admitted into the uncut stand by cutting clear the adjoining strips often effects the establishment of adequate reproduction beneath the standing timber, even though this timber has not been thinned. The simplest and most satisfactory way of reproducing the strips left after the first cutting, if natural regeneration fails to become established, is to cut them clear and plant. This combines natural reproduction on the first strips with artificial on the second.

In Figure 4, 50 per cent of the area has been assigned to strips to be cut in the first operation, and 50 per cent has been left for the

second operation. This proportion is not a requirement of the strip method (see Fig. 6). From 30 to 70 per cent of the area might be cut in the first operation. Owing to the greater difficulties in securing natural reproduction on the strips cut in the second operation, 60 to 70 per cent (roughly two thirds of the area) ordinarily should be cut over in the first operation. By making the uncut strips only

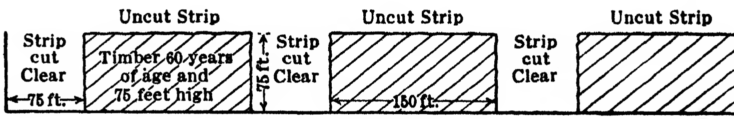

FIG. 6.

Alternate strip method, where one third of the area is cut clear in the first cutting. The cut strips are half the width of the uncut strips and equal in width to the height of the timber.

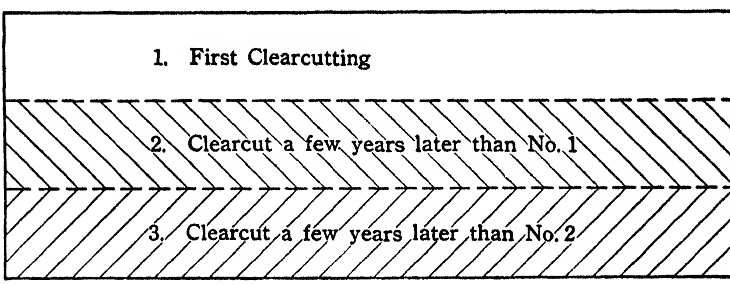

FIG. 7.

A simple example of a small stand reproduced under the method of clearcutting in progressive strips.

half as wide as those cut this proportion is obtained. There is danger in making the uncut strips too narrow. They must be wide enough to offer protection to the cleared area and to be windfirm in storms, and they must be large enough to make the second operation practicable as a logging proposition. In general the strips left should be at least as wide as the height of the timber.

Some windfall must be anticipated along the edges of the cleared area. It can be minimized by careful selection of the trees to be left on the borders of the strips. The strips cut for most species will range in width from one to four times the height of the stand.

(*b*) *Progressive strips.* In this method three or more operations are required to remove the timber from the entire stand. As it is applied in its simplest form, strip cuttings are made at short intervals starting at one side of the stand and advancing progressively across to the other side (see Fig. 7).

The entire series of cuttings must be finished within a short enough period (10 to 20 years, depending on length of rotation) to make the new growth on the whole area evenaged, if the method is to be classed as clearcutting. In large stands this simple form of progression is impractical, since the entire area could not be cut over in a short enough time to produce evenaged timber, at the same time keeping the individual strip narrow enough to reproduce successfully, unless more than one cutting section is established.

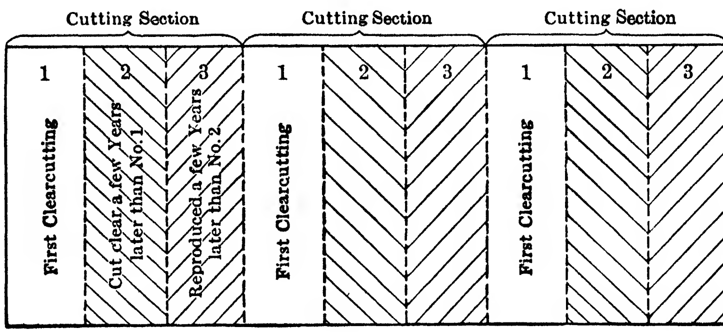

FIG. 8.

Clearcutting in progressive strips, using three cutting sections. The last strip (No. 3) in each section may be reproduced by a method other than clearcutting.

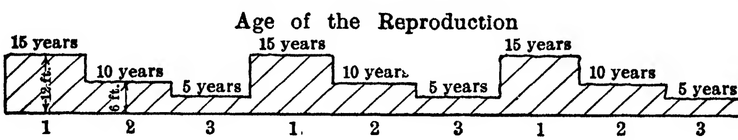

FIG. 9.

The same stand as shown in Figure 8, but 5 years after the clearcutting and reproduction by planting of the strips marked 3. Despite the present difference in height and age the stand is evenaged.

To overcome the difficulty several cutting sections are laid out as shown in Figures 8 and 9, and operations are started at the same time within all these cutting sections. Strips sufficiently narrow so that seed can be disseminated over all parts of the area cleared are cut across each cutting section, and the process is repeated at intervals of a few years until the entire area is clearcut. A large stand can be cut under this arrangement with as much protection to reproduction as may be secured in a small stand with a single cutting section. The uncut portions of each cutting section furnish seed and protection to seedlings. Each successive cutting should follow its predecessor as soon as reproduction is established on the last strip cut. This may

vary from 2 to 5 years. If natural reproduction has not started in satisfactory amount at the end of 5 years, artificial reproduction should be employed.

When the time comes to cut the last strip of the cutting section artificial reproduction must be used or natural reproduction must be secured by some other method. The width of the last uncut strip can be reduced to a narrow belt of timber, and in this way the part of the whole area which must be regenerated artificially may be kept at the minimum.

Where the topography is rugged and irregular, where soil conditions show a wide range within relatively small areas, and where the evenaged stand is lacking in uniformity, the regular arrangement of cutting areas necessary under the strip method is impracticable. Instead, the portions cut may be of irregular shape and distribution.

In the first cutting, irregularly shaped areas or patches are selected which for some reason should be cut before the rest of the stand. Succeeding operations carry the clearcutting over the entire stand. A patch of injured trees or an opening in which seedlings are already springing up and needing more light may determine the location of the first cutting. Timber on swampy ground or on rocky knolls which, if left exposed by adjacent cutting, might be windthrown may be included in the patches cut in the first operation. Frequently the shape of the hills and direction of the slopes make an irregular and patchy arrangement of the cutting areas advisable.

The question may arise about the advantage, if any, in distinguishing these modifications of the clearcutting method. After all, cutting alternate strips or progressive strips clear may be interpreted as cutting the whole stand clear — each relatively narrow and small strip cut clear being considered a whole stand by itself. It is quite possible to make such a subdivision of the area and to recognize only clearcutting the whole stand. However, in both modifications, a number of strips close together are clearcut within a sufficiently small fraction of the rotation so that the new crop as it develops merges on all the strips into one evenaged unit which usually is considered to be a single stand. If each alternate or progressive strip is recognized as a stand by itself, the stand pattern of the forest becomes exceedingly complicated, and the requirement for successful natural regeneration of having seed woods capable of producing seed always adjacent to the stand currently clearcut may be difficult of arrangement.

Cutting in strips is practiced under some other reproduction methods than clearcutting. For example it may be used under some modifica-

tion of shelterwood and selection. Where strips are cleared under these systems, the strip so treated is so narrow that the adjoining timber furnishes good protection from the side to the physical factors of the site and helps to conserve soil moisture. Such strips would ordinarily be restricted in width to not over half the height of the adjoining timber. If wider than indicated by such proportion, strips would be classed as clearcuttings; if narrower, they may be strip fellings under another reproduction method.

Advantages and Disadvantages of the Clearcutting Method. *Advantages.* 1. The best method for stands of overmature timber and for mature timber of large size. Silviculturally and financially such stands are ready for utilization. It is usually poor silviculture, as well as more expensive, to cut stands composed principally of large mature or overmature timber otherwise than clear.

2. Concentrates logging on relatively small areas containing the timber to be harvested. This tends to keep logging and transportation costs low.

3. Avoids damage to young growth in the logging operation since young growth is concentrated on areas other than those being logged.

4. Avoids loss of timber by windfall. Frequently on exposed slopes and ridges, on shallow soils, and in swamps where surface root development is forced, clearcutting is the safest method. There is some evidence that in swamps the interlacing root systems of the trees, located as they are in the moist, spongy, upper soil layers, sway and yield with the force of the winds but are not uprooted (LeBarron 1945). On soils which become saturated with moisture at seasons of the year when heavy winds prevail, clearcutting should be practiced. With species shallow-rooted in habit the necessity for clearcutting is greater than with deep-rooted species.

Trees which have been grown under conditions of dense stocking have restricted crown development and a correspondingly weak root system. With such timber, clearcutting is often the only safe method of treatment.

5. Furnishes a bare exposed seedbed with full overhead light for the start of natural reproduction. Allows development of the young stand in full light and free from root competition of the old stand. Where such a condition is demanded by a given species for best reproduction clearcutting should be employed. Where unincorporated humus or any thick forest floor occurs, its decomposition usually can be hastened by clearcutting. On such soils the supply of available nitrogen may be increased as an indirect consequence of the heat brought to the exposed soil.

6. Is simple and easy to practice and hence does not require a forest staff made up of as highly skilled men as the shelterwood method or some forms of selection, where skillful marking of trees to be cut is essential to success. Inspection of the operations and control of the output are easy.

7. Since the period of regeneration in each stand is confined to a small portion of the rotation, permits use of the area for grazing during the remainder of the time should such use be profitable and cause no injury silviculturally. Only in special locations is this point of consequence, as in most forest types well-stocked stands do not provide forage.

8. When it is desired to change the species to one not now found in the stand, clearcutting with artificial reproduction is the effective method.

Disadvantages. 1. Temporarily destroys the forest cover, causing a change in the microclimate of the area which may last for many years. This induces conditions which for some species and on some sites are adverse to the growth of seedlings and render uncertain the establishment of a satisfactory reproduction. Such results may come from:

(*a*) Deterioration of the physical factors of the soil. Moisture relations often are affected unfavorably, wet soils particularly in cold climates becoming more swampy and dry soils in some cases tending toward greater dryness in the surface layers. On the other hand, where deposits of unincorporated humus cover the soil, clearcutting may assist in decomposition and therefore improve rather than injure soil conditions. Sometimes there may be too great accumulations of undecomposed humus, and clearcutting at the end of the rotation serves to remedy this condition (Fraser 1934).

Clearcutting of the forest may be expected to result in a raising of the water table because of a decrease in transpiration and, if heavy slash covers the ground, a decrease also in evaporation. This is true not only of swamps but also of upland areas. Only on certain swampy sites, however, is the change of critical importance in affecting the establishment of reproduction or in other use of the land.

As the forest becomes reestablished after clearcutting, the water table may be expected to return to its former level.

Wiedemann (1928) expresses the viewpoint that sometimes harmful effects and at other times beneficial effects to the soil will predominate. Wittich (1930), though he does not recommend clearcutting everywhere, concludes that the bad effect of exposure following clearcutting has often been exaggerated, and that exposure may

afford a soil the opportunity for rest and recovery that it needs after having been long under forest.

(*b*) Appearance of a grass, brush, and weed growth which competes too successfully with reproduction.

(*c*) Exposure of reproduction to the drying influence of sun and wind and to injury by frost.

(*d*) Greater activity of insects than occurs where reproduction is secured under the shelter of older trees.

2. Affords relatively poor protection against erosion, landslides, snowslides, and rapid runoff of water. In its protection value to the area on which the forest stands and indirectly to other lands the clearcutting method ranks lowest and selection highest.

3. Is esthetically the least desirable of the four high-forest methods, chiefly because of the regularity in age arrangement into which the stands are forced.

4. Cannot be used effectively unless the market will absorb all the material on the area. Where the trees are all large and sound, clearcutting is practicable. If numerous small trees occur, as often happens in stands of merchantable timber, or if many defective trees are present, a market must be found for small and defective material or else trees containing such material must be cut or otherwise disposed of at a loss, if clearcutting is practiced.

5. An alleged disadvantage is that, when the clearcutting method is applied for several rotations, the capacity of the site to produce wood crops may be reduced. Such a result, coming from deterioration in the physical condition of the soil as a consequence of its complete exposure at the end of each rotation, has been reported in some places (Wiedemann 1924). It is not likely to occur on the better soils. Evidence to prove the point is limited, and caution should be exercised before assigning, in any region, decrease in productive capacity to clearcutting alone. Bad management in other ways, particularly in growing species unsuited to the site, may be a greater factor in decreasing production than the clearcutting method. This subject can be investigated only in regions where forestry has been practiced for several crop rotations by both clearcutting and other reproduction methods.

A study of Scotch pine stands at Eberswalde, Germany, showed that there was no site deterioration due to the practice of clearcutting with artificial reproduction (Hennecke 1932). In fact, improvement in soil conditions was noted.

The more serious disadvantages of clearcutting are those relating to the complete removal of the forest cover and consequent temporary

exposure of the area. Climate plays a large part in determining how important such disadvantages may prove for any given forest type and region. There are regions, as for example the Lake States, where clearcutting, if practiced at all, should be employed with great caution because of the severe climate. In other regions like the Pacific Northwest, New England, and the southeastern United States, because of the relatively favorable climates, small importance is attached to disadvantages of the clearcutting method. In any forest, irrespective of climate, the disadvantages of clearcutting may be minimized as the size of the individual clearcut area is reduced, but correspondingly the advantage of concentrating logging on one area is lost. This point, namely the effect of the size of the individual area clearcut on the successful employment of the clearcutting method, often seems to be overlooked. One reason for this undoubtedly is that the method is confused, in the minds of many observers, with the old-style clearing of the forest over great areas by loggers, wherever all the standing trees could be sold for timber, without any consideration for obtaining reproduction after cutting. Such operations are not examples of forestry practice and should never be confused with clearcutting as a recognized reproduction method. Proper application of the method requires not only the harvest of the mature timber but also the establishment of a new crop.

In European practice clearcuttings are often classified on the basis of width. Wiedemann (1926) in utilizing such a classification for Scotch pine defined clearings as *narrow* (½ to 1 times tree height), *wide* (1 to 3 times tree height), and *great* (more than 3 times tree height). When only *narrow* clearcuttings are used dangerous results likely to accrue from exposure of the site are of small consequence. There may even be a question, if the species grown are light demanding, whether the opening is wide enough for their satisfactory development.

Application of the Clearcutting Method. Clearcutting, particularly with artificial regeneration, because of its simplicity and the high production of valuable timber possible in its evenaged stands has been, and is being, used frequently in countries where forestry has been practiced longest. As forestry practice develops in this country there will be many opportunities for applying properly the different variations of clearcutting. Climatic conditions in many parts of this country are so favorable to conservation of the site, to vigorous forest growth, and to the establishment of natural regeneration that there will always exist a wider opportunity for the successful em-

ployment of the clearcutting method here than in less-favored lands. Furthermore, several of our valuable commercial trees possess characteristics that enable them to start and develop successfully on clearcut areas.

In general, clearcutting is best adapted for use on fertile soils, under favorable climatic conditions, with species which are gregarious by nature and with those which prefer an exposed seedbed. With such species even poor soils do not prevent successful employment of clearcutting. Many conifers, such as Douglas-fir and several of the southern pines, have the ability to reproduce naturally after clearcutting. Cuttings in virgin timber, owing to the large size and maturity of all individuals, are often of this type. On the other hand clearcutting in northern hardwood stands in the Lake States, for example, may cause a serious change in forest conditions.

Clearcutting with natural reproduction, where seed comes from trees outside the area cut over, is suitable only for light-seeded species capable of starting on exposed areas. Virginia pine, in the region of its best development on the Piedmont Plateau, and loblolly pine on the Atlantic coastal plain can be successfully reproduced by this method. Many illustrations of successful natural reproduction of loblolly pine on clearcut areas by seed blown in from adjoining uncut timber can be seen throughout the commercial range of this tree. One, illustrated in Figure 10, shows the influence which condition of seedbed may have on the amount of reproduction. Both cultivated land and bare soil from which a thick forest floor has been removed are good seedbeds for loblolly pine reproduction, although the former is the better. In this example too abundant reproduction has started on the formerly cultivated field.

Douglas-fir, growing in western Oregon and Washington, also is able to restock clearcut areas by wind-blown seed disseminated from uncut bodies of timber located adjacent to the clearcut areas. The relatively great height of the uncut timber (sometimes more than 200 feet), and the favorable soil and climatic conditions, are influential factors in securing satisfactory natural reproduction of Douglas-fir on clearings. The *Forest Practice Handbook* for the Douglas-fir region (Anonymous 1937) states that clearcut areas will need to be within ¼ mile of mature timber, in order to be reproduced naturally within a reasonable time. Since 50 per cent of Douglas-fir seed falls within 200 feet of the seed source, and abundant seed crops come only once in 3 to 4 years, it may take several years to accomplish reseeding unless the winds happen to be particularly favorable. Blocks of timber at least 3 to 5 acres in size are needed,

even with favorable winds, to ensure reseeding for a distance of ¼ mile. One plan, among several which are recommended, is scattering the clearcut areas so that they will be adjoined and interspersed by strips or blocks of uncut timber, which would be reserved from cutting until at least two seed crops had matured, or for a period of 5 to 8 years. After this time the uncut timber could be removed. This would be a crude application of clearcutting in alternate strips or patches with the seed supply coming from the uncut strips.

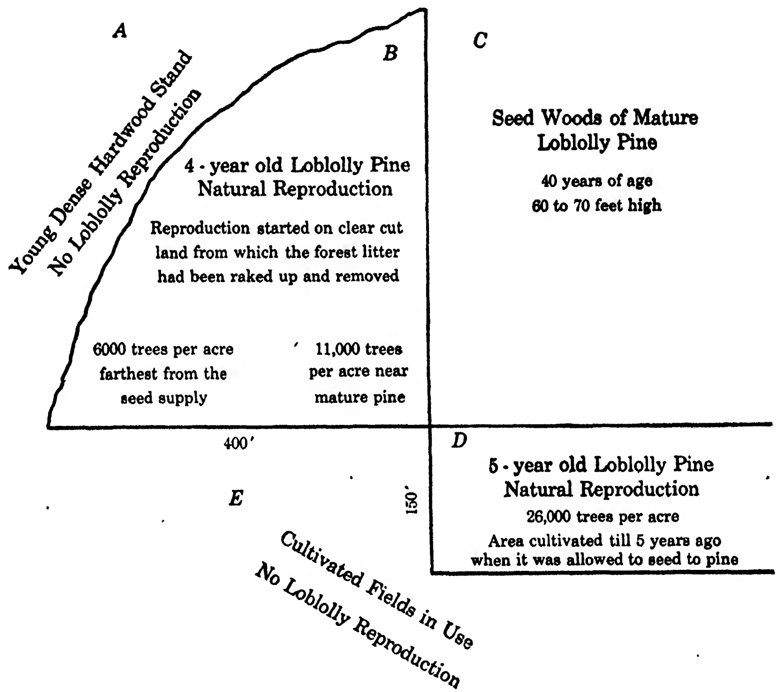

FIG. 10.

Natural reproduction of loblolly pine as influenced by seedbed and by location with respect to seed source.

Person and Hallin (1942) investigated the dissemination of redwood seed on cutover areas and concluded that regeneration, from blocks of uncut timber 250 feet or more high, was not satisfactory beyond 330 to 400 feet downhill or 200 feet uphill from the seed-bearing timber. The width of the area cut clear could average 600 feet and be adequately restocked. This is far short of the 2000-foot width needed in effective use of slack-line yarding, the logging method usually employed in clearcutting redwood.

The Weyerhaeuser Timber Company on their Longview, Wash.,

operation, where Douglas-fir is the chief species, practice clearcutting in mature stands on relatively small areas. Natural reproduction is obtained from nearby seed sources, on most of the area. Conklin (1941) states that on lands cut in this manner 5 years or more ago 50 per cent of the area is adequately stocked, 30 per cent needs some planting to make the new stand fully stocked, and only 20 per cent of the area, partly made up of rock bluffs, is barren of reproduction.

A good example of clearcutting with natural reproduction, the seed supply coming largely from cones stored for years on the trees removed in the cutting, is found in evenaged, overmature lodgepole-pine stands. Portions of the lodgepole pine forests in the Rocky Mountains consist of relatively evenaged stands of overmature timber usually over 200 years in age. A partial cutting in such stands ordinarily is followed by the loss of the uncut trees through windthrow or other causes. Clearcutting is advised, leaving the unused tops of the trees scattered over the ground. The persistent unopened cones, representing several seed crops, attached to these tops open after the cutting and release sufficient seed to stock the clearing abundantly.

Jack pine is another species that can best be reproduced by clearcutting. The fact that the cones are persistent and remain closed, distributing very little seed from standing trees, together with the intolerance of shade characteristic of jack pine seedlings, precludes successful use of partial cutting methods in reproducing this species. Two conditions must be met in applying clearcutting in jack pine stands. In the first place the mineral soil must be exposed. This is best accomplished by tearing up the underbrush and mixing the unincorporated humus with the mineral soil, so that at least 60 per cent of the area has mineral soil exposed. A second disking of the area at right angles to the first probably will be needed to expose the soil adequately. The equipment needed for this work is a rugged disk plow drawn by a tractor. The second point is that the small cone-bearing branches of the felled trees must be scattered on exposed mineral-soil surfaces. Zehngraff (1943) reported the cost of such treatment at $4.14 per acre for the disking and $5.01 per acre for scattering slash. The disking should be done just before the cutting; if it is done earlier, vegetation springs up on the exposed soil and seriously competes with the jack pine seedlings. If disking is done right after the cutting, as sometimes may be necessary, the slash has to be piled before the disking and afterwards the cone-bearing branches must be selected and scattered over the exposed mineral soil.

When the clearcutting can be made immediately after an abundant seed year, thus utilizing the current seed crop from the trees cut, the method can be extended in its application to a broader range of species.

Clearcutting the whole stand is especially suitable for areas to be reproduced artificially or where, in an organized forest naturally reproduced, the area included in a single stand is small. The strip modifications are useful in extensive stands or where detailed and intensive practice is possible. As yet they have been used to only a small extent in this country. Clearcutting in alternate strips is advised for Atlantic white-cedar swamps along the Atlantic Coast (Korstian and Brush 1931). The seed of this species is very light and is produced in large quantities. Light is needed for successful development of the seedlings. Good markets for small posts and stakes lead to close utilization and make clearcutting possible. Danger of windfall because of the high water table and shallow root system makes a scattered-seed-tree method impracticable. The strips cut should be not over 1000 feet in width with uncut strips left between those cut. Since mature stands of Atlantic white-cedar do not usually exceed 70 feet in height, one half the width of the clearing approximates 7 times the height of the adjoining stand.

Clearcutting in alternate strips has been used to a small extent in stands of high-quality, mature western white pine. Clearcut strips 300 to 450 feet wide running at right angles to the topography alternating with uncut strips 150 feet wide have been reproduced successfully (Haig, Davis, and Weidman 1941, pp. 81-85). The method should be restricted to the more favorable sites. The securing of regeneration on the uncut strips has been found difficult in application. To accomplish this the uncut strips should be broadened and in the first cut have about 60 per cent of their volume removed in a shelterwood cutting. The timber left should regenerate both the clearcut and partially cut strips. Davis (1942, p. 19) estimates the cost of such a system of clearcutting in alternate strips at $56.80 per acre made up as follows:

Piling and burning slash	$6.50 per acre
Disposal of defective and unmerchantable trees by pile and burn methods	11.20 " "
Seed trees	22.90 " "
Broadcast burning	16.20 " "

This is considered a less expensive method than reserving scattered seed trees, but it is more costly than clearcutting and planting.

Clearcutting in alternate strips has been suggested for the Engelmann spruce type in Colorado as a good substitute for the salvage-group selection method of cutting (Connaughton 1943, p. 43). The width of the strips cut and those left uncut should not exceed 66 feet. A light salvage (at least of dead-topped trees) in the reserve strips can be made at the time of the first cut. Approximately 50 per cent of the total merchantable volume would be removed at the first cut.

In Engelmann spruce stands the advantages of clearcutting in alternate strips over the group-selection method appear to be that maximum protection from wind is provided for the submerchantable stand on the clearcut strips and that scarification of the seedbed by heavy equipment, which should assist the regeneration of Engelmann spruce, could be accomplished with least injury to the reserve stand. The chief disadvantages of the clearcutting method are its radical deviation from present operating practice and the possibility of higher logging costs than in applying group selection.

A study of loblolly pine seed production and dispersal by Jemison and Korstian (1944) indicates that clearcutting in alternate or progressive strips can be successful in regenerating stands of this species. The cut strips may be 150 to 200 feet in width if bordered on the windward side by well stocked stands of seed-bearing timber. A period of 5 years following the cutting should be sufficient to establish a new crop of 1000 or more seedlings per acre. In fact such reproduction may be obtained as the result of one abundant seed crop.

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CHAPTER V

THE SEED-TREE METHOD

Definition. The area is cut clear except for certain trees (called seed trees) left standing singly or in groups for the purpose of furnishing seed to restock the cleared area naturally. Only a small percentage of this total volume, ordinarily less than 10 per cent, is left standing as seed trees. (See Fig. 11.) After the new crop is established these seed trees may be removed in a second cutting or left indefinitely. If left they usually are a total loss, rarely surviving in a sound condition until the end of the second rotation.

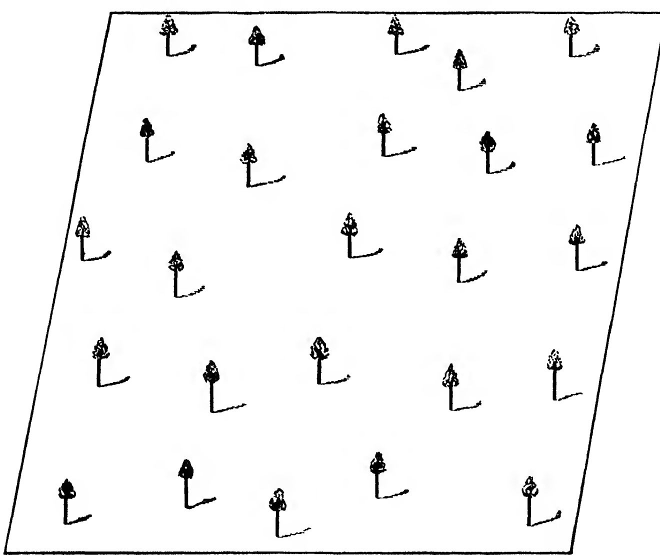

FIG. 11.

A stand reproduced by the scattered-seed-tree method, leaving approximately one seed tree per acre in fairly even distribution.

In some classifications the seed-tree method has been included under clearcutting methods. The leaving of some trees, together with the fact that the seed supply is furnished by these seed trees standing on the area cut over, instead of by trees cut in the clearing operation or by trees standing outside the area cleared, warrants the separation into two methods.

Form of Forest Produced. The seed-tree method requires for its application the same form of stand as clearcutting, namely, either evenaged or, if containing more than one age class, with all trees of merchantable size. As a result of the seed-tree method an evenaged stand is produced. There may be a difference of 10 to 20 years in age between the young seedlings which start on the cutover area but not enough difference to prevent the stand from being evenaged.

For a number of years immediately after the first cutting the stand presents a two-storied appearance, the seed trees forming the upper story and the reproduction the understory.

Under exceptional circumstances some or all of the seed trees may remain throughout the rotation. Where this occurs the stand may be termed either evenaged or two-storied, depending on the number of seed trees and the percentage of the area occupied by them.

Details of the Method. In the simplest form of the seed-tree method the seed trees are left standing isolated as individuals after the removal of 80 to 90 per cent or more of the volume of the stand. Natural reproduction springs up under and around the seed
sufficient quantity to form a new stand. If conditions a
a single seed year may suffice to accomplish this.
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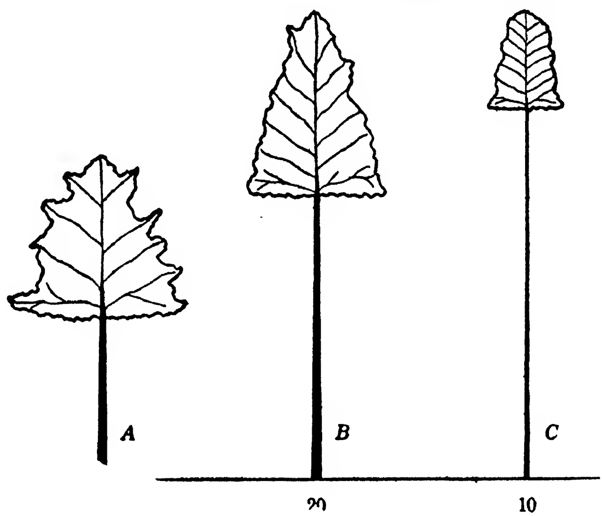
tional development of crown are less likely to blow down or break than tall trees.

The seed trees must be old enough to produce abundant fertile seed. The age at which seed bearing begins in closed stands is the point which should be considered. From the practical standpoint it is unlikely that an age for harvesting the timber crop will be set so low as to antedate the period of abundant fertile-seed produc-



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formed or else left during the rotation, usually to die before being harvested with the second crop. The selection of the seed trees depends upon which of these two plans is to be followed.

If a second cutting can be made within a few years and the seed trees be utilized, then fine, healthy dominant trees, presumably the best seed producers and containing valuable timber, may be selected. Where the seed trees are going to be left and must be considered as a total loss, trees of a lower commercial value may have to be chosen. They may be the deformed or limby trees or trees attacked by fungi or simply the smaller trees.

Under the conditions created by development in evenaged stands (for which the seed-tree method is best suited), the smaller trees will be the lower-class and weaker individuals. Such trees are not and cannot at once become prolific seed producers. A period of several years may be lost before they are able to start the establishment of reproduction. It is also possible that these smaller trees may possess less than the average growth vigor since they were not the dominant individuals in the stand. In unevenaged stands these objections to individuals of the relatively smaller size classes as seed trees are not valid.

In general, it is unwise to leave poorly formed individuals, unhealthy trees, or trees suffering from injury by insects and fungi, because of the probability that the offspring from such trees may inherit certain unfavorable characteristics from the parent, as, for example, a low vigor in resisting disease (Roeser 1926). Existing economic conditions may sometimes force the use of unsuitable seed trees, but as soon as possible a better practice should be adopted.

More definite information about inherited characteristics of forest trees is needed. Meanwhile it is best to be on the safe side and when practicable leave only seed trees of the best type.

In some stands of virgin timber the only seed trees practicable to leave may be trees affected with heart rot. That this can be done with Douglas-fir without serious danger to the new crop is evidenced by the following quotation from Munger (1927):

"The wisdom of leaving conky trees for seed has been questioned. This need not be gone into here more than to say that the prevalent fungus which causes conk rot (*Trametes pini*) is a disease of the heartwood, and therefore does not affect the vitality of the tree; that the disease is not transmitted through the seed; that it is a disease of old trees and therefore not to be greatly feared in the new crop which will be harvested probably before it comes to the age of bad infection. Foresters and pathologists are agreed that the leav-

ing of such trees does not practically increase the danger of infection in the new crop and that the cutting of these few conky trees merely to rid the area of infection would be a trifling measure, so universal is the disease."

Number and Distribution of Seed Trees. After the kind of seed trees to be left has been fixed the number per acre must be decided. The amount of seed produced per tree, the size of the tree, the percentage of the seed that will germinate and finally become established as seedlings, and the distance to which seed can be disseminated are among the principal determining factors. The very nature of the method requires that it be applied only with relatively light-seeded species relying upon wind dissemination of the seed. Ample seed to restock all portions of the area must be provided. As a general rule with light-seeded species satisfactory dissemination of seed can be counted on for a distance from the tree at least equal to the height of the tree and with some species for distances of 2 to 5 times the tree height. The amount of seed produced per tree usually is the limiting factor in determining the number of trees to leave rather than the maximum distance of seed dissemination. With large individuals of a decidedly light-seeded species 1 tree per acre may be enough. The same species in small-sized second-growth timber may require 10 per acre. A prolific seed producer, but with a heavy seed, may need a similar number to ensure uniform distribution. With site conditions favorable to germination and establishment of reproduction fewer seed trees will be needed. Whether reproduction is to be secured in one or during several seed years and whether the seed trees will be cut in a few years or remain also affect the number that can properly be left. From 1 to 10 seed trees per acre may be regarded as the usual number.

If more than 10 are left the crown spread of the seed trees occupies a considerable part of the area and the method begins to resemble shelterwood. At the other extreme a species is rarely found capable of disseminating the seed and thoroughly restocking an area if less than one seed tree per acre is retained.

The proper number of seed trees to leave per acre cannot be settled until an intensive study of seed production and the early development of reproduction has been made for the species in question. First, an arbitrary standard must be set indicating the minimum number of seedlings per acre safely past the period of establishment which may be considered a satisfactorily stocked stand. For example, this minimum might be placed at 1000 trees per acre at the tenth year. The next step is to determine, after allowing for losses to the seed be-

fore germination and to the seedlings after germination, the amount per acre of seed needed to secure an established reproduction of the prescribed density. When the total amount of seed per acre is known the number of trees required to furnish the seed should be calculated.

Seed production ranges from nothing in years of failure to large crops at more or less regular intervals. Aside from this seasonal fluctuation seed production under normal conditions varies with the crown development (leaf surface) and the vigor of the tree. Thrifty individuals with large crown development will produce more seed than weak, small-crowned trees. Vigor is considered more important than actual size of crown. Seed production must be determined for trees of different sizes, and thus the number of seed trees of any given size (diameter) necessary to leave can be estimated.

In theory it will be possible to form a number of combinations based on size of the trees and secure an equal production of seed in each combination. For instance a few trees of large diameter or several of smaller diameter may be left. The best combination from the practical standpoint is the one which reserves the smallest merchantable volume while providing for the requisite amount of seed per acre. To determine this relation, seed production per tree can be related to the volumes in different-sized trees and ratios secured of volume to number of seed produced. In a study of seed production by longleaf pine Chapman (1926) found that the maximum production of seed per tree occurred in the 16-inch (diameter breast high) size but that a 13-inch tree 40 feet in height produced the most seed per board foot of volume contained and hence was the most economical tree to leave. Not less than four 13- to 16-inch trees should be left per acre or a volume of 300 to 660 feet, board measure, per acre.

The actual merchantable volume per acre left standing in the scattered seed trees is likely to range from 500 to 2000 feet, board measure.

If a species is dioecious, both female and male trees must be left. White ash and cottonwood furnish examples.

In order to secure adequate reproduction on all parts of the area uniform distribution of the seed trees should be attempted. However, it is more important to select the proper individuals to serve as seed trees than to attain an absolutely even spacing. Where the topography is uneven it will generally be best to leave a majority of the trees on the higher ground, from which vantage points they can scatter seed over the lower areas.

Destruction of the seed by rodents may be a serious factor. If the

supply is restricted to a few seed trees per acre the rodents may take the entire crop.

Cultural Operations. Just as in the clearcutting method, provision for an abundant seed supply is not sufficient, for in addition, favorable conditions for germination and early growth of seedlings must be established and maintained for a few years. Failure to apply the scattered-seed-tree method successfully may often be traced to neglect of this requirement. For details about the kind of treatment required, see the section entitled "Preparation of the Cutover Area Preliminary to the Establishment of Reproduction," given in Chapter IV but applying also to the seed-tree method.

The scattered seed trees assist in conserving surface moisture and in protecting reproduction from injury by frost.

Removal of Seed Trees. When enough seedlings to make a full stand have become established, the purpose for which the seed trees were left is accomplished. If it will pay financially the seed trees can now be removed, leaving the new stand to develop unhampered. A portion of the reproduction will be destroyed in this cutting but not enough to affect the new stand seriously. If a second cutting of this sort is not feasible the seed trees are allowed to grow. Some few may live to be cut when the new crop is harvested and furnish material of exceptional size and quality. Most of them will succumb to the ravages of insects or fungi. Trees grown through life in a closed stand and then suddenly placed in an exposed position as seed trees suffer through changed site conditions and are apt to be weakened, suffer sunscald, or become stag-headed, and they are susceptible to insect and fungi attacks.

The seedlings may start immediately after the first cutting or not for several years, depending on the occurrence of a seed year. If enough seedlings do not appear within five years it is unlikely that reproduction can be secured by natural means — certainly not unless the expenditures for preparation of the site are repeated. The blanks should be filled by planting.

Modifications of the Method. *Group-Seed-Tree Method.* One of the common variations is to leave the seed trees in groups instead of scattered singly over the area, the purpose being to minimize the danger of the seed trees being windthrown or broken. It is based on the theory that a group of trees together will stand unharmed against winds which would overturn or break the same trees standing singly. This is probably true if all the trees available are relatively slender and small crowned. Such trees may have greater strength as a group than singly. In opposition to this, field observations indicate

that sometimes groups offer a greater resistance to winds (Munger 1917), which are thus enabled to exert greater force against the group and often overturn or break all the trees in the group.

The size and quality of the seed group have of course great influence in determining its windfirmness. To be reasonably immune from windthrow a group should have length and breadth at least equal to its height. On exposed ridges or in moist ground groups even of this size might be overthrown. The trees on the edge of the groups preferably should have live branches extending to the ground or at least have a deep live crown. Groups low at the edges and rising gradually to their greatest height in the center are relatively safe from wind damage. Groups with breadth and width equal to their height usually are impracticable, requiring too great an investment for securing natural reproduction. Seed groups as ordinarily employed contain from 2 to 10 trees of merchantable size, sometimes protected by considerable numbers of small trees.

Except in reducing danger to the seed trees from wind, the group-seed method has nothing to recommend it in contrast to scattered seed trees. The distribution of seed to all parts of the area cannot be so uniform unless a larger percentage of the total volume of the stand is reserved in the seed groups. If only the small volume percentage is retained as in the scattered-seed-tree method, the distances between groups will be longer on the average than those between single seed trees and are likely to become so great as to prevent dissemination of the seed over the entire area. Reproduction is affected not only by the poorer distribution of the seed but also by reduction of the slight amount of protection to soil and seedlings afforded by the scattered seed trees. (See Fig. 13.)

In a mixed stand a windfirm species sometimes can be included in a seed group for the purpose of furnishing support to a species easily windthrown which it is desired to reproduce. There is danger of course that the windfirm species may establish its own reproduction.

Reserve-Seed-Tree Method. Under certain conditions the seed-tree method may be applied with the idea both of securing a new crop of natural reproduction and of reserving a portion of the mature stand for rapid increment during a second rotation. In this modification of the method the seed trees are selected for their capacity, not only to furnish seed, but also to grow rapidly and remain thrifty during a second rotation. At the end of this second rotation the new crop is harvested together with the seed trees left at the beginning of the rotation. Some timber of exceptional size is produced.

The reserve-seed-tree method is not suitable for every stand. For its successful application the stand must be of moderate age when reproduced, with the individual trees still thrifty and capable of withstanding the change in site conditions due to the cutting, and of responding with increased growth. In stands past maturity this method is inapplicable.

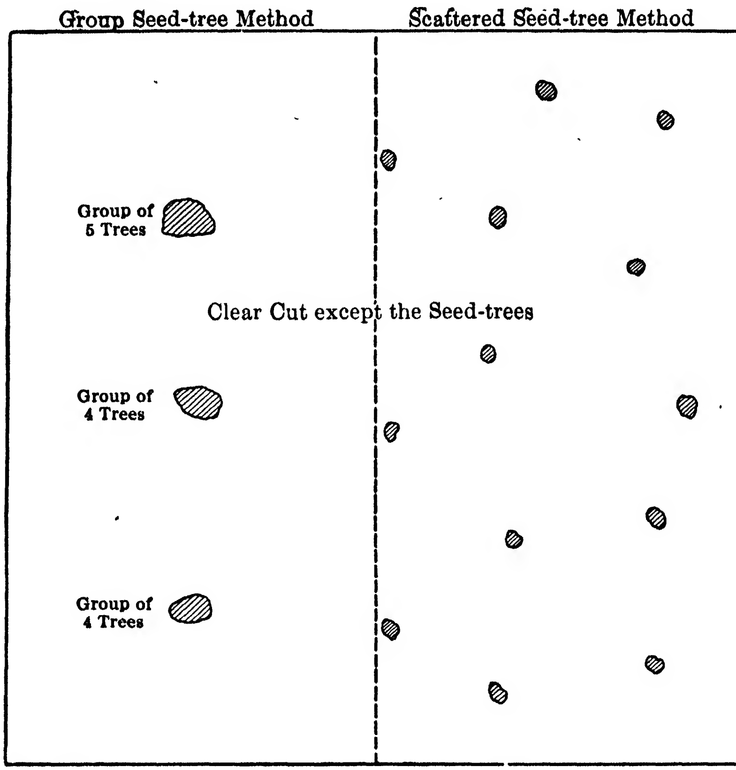

FIG. 13.

A comparison of the group- and scattered-seed-tree methods where the same number of trees (and volume) are left in the stand for each of the methods. It is evident that dissemination of seed cannot be so uniform when the seed trees are arranged in groups as when they are distributed singly. The shaded areas indicate the portions of the tract occupied by the crowns of the seed trees.

Trees of as little present commercial value as possible are chosen, but they must be dominant, thrifty trees. As a rule healthier and better-quality trees are left as seed trees than under the scattered-seed-tree method. The number of reserve seed trees may vary, depending upon whether emphasis is placed on the development of the young stand or on the timber to be secured eventually from the seed

trees. If the new stand is to develop properly the reserve seed trees must be relatively few. If production of large timber is of primary importance, the seed trees may be left as close together as rapid growth of the individuals will warrant. A distance of at least 40 feet should be left between the stems of the reserve seed trees. This would allow for about 25 seed trees per acre as a maximum.

The reserve-seed-tree method maintains a two-storied form of forest (see Fig. 14).

The advantages of the reserve- as contrasted to the scattered-seed-tree method are: better reproduction is obtained, owing to the larger seed supply and increased protection furnished by the greater number of trees; some large timber is produced.

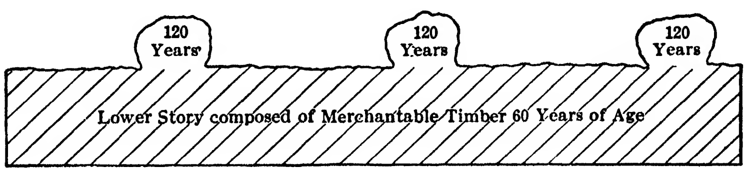

FIG. 14.

A stand ready to cut containing reserve seed trees. The form is two-storied. The large reserve seed trees will be removed and thrifty individuals selected from the lower story to remain during another rotation.

The understory, when harvested, is likely to be of low yield and poor quality because of interference from the upper story.

Fire Seed Trees. It has been the practice of the United States Forest Service to retain, on certain cutover areas, single scattered trees, which may be termed fire-insurance seed trees. These trees have been left after the final cuttings in various modifications of the clearcutting, seed-tree, and shelterwood methods. Usually either reproduction had already been established at the time the fire seed trees were left in their isolated position or other sources of seed supply were counted on to complete the reproduction. The purpose of the fire seed trees is not, then, primarily to establish the second crop. These trees are left as a fire-insurance measure particularly on large cutover areas and in regions of great fire danger. If the reproduction is destroyed by fire the seed trees, on account of their size and hardiness, are expected to escape and to provide the seed for restocking the burn. Sometimes occasional large thick-barked Douglas-fir which would escape fire have been left, together with thrifty, younger seed trees which would be killed by a severe fire. Species that are exceptionally fire resistant make ideal fire seed trees. Western larch is

one of the best examples. This species has sometimes been left as fire seed trees in the western white pine forests in northern Idaho.

Fire-resistant species cannot always be found to serve as fire seed trees. Ponderosa pine seed trees, though not as strongly fire resistant as western larch, are sometimes left for seed insurance purposes in case of fire on timber-sale areas in the ponderosa pine type in the Rocky mountains. If less-resistant species are used there is a question whether the fire that destroys the reproduction will not also kill the seed trees. It is also an open question whether the fire seed trees can successfully restock a bare, burned area. If site conditions are unfavorable for natural reproduction, it is unreasonable to expect restocking by scattered seed trees. If site conditions are favorable for natural reproduction it is likely that a new crop could be established artificially. It is, therefore, questionable whether the financial investment in leaving fire seed trees (unless of an exceptionally fire-resistant species) is always justified. It may be cheaper to clearcut and to replace by artificial methods the occasional bodies of reproduction consumed by fire. Nevertheless, when the fire danger is great and artificial regeneration on a large scale following fires might be needed over extensive areas, the leaving of fire seed trees can sometimes be justified. Possibly increasing the efficiency of protection against fire may be a cheaper way of keeping the lands properly stocked.

Advantages and Disadvantages of the Seed-Tree Method. *Advantages.* 1. It concentrates logging on relatively small areas, thus tending to keep logging and transportation costs low.

2. It furnishes a bare, exposed seedbed for the start of natural reproduction and hence may be a good method for those species which require such a germinating bed.

3. It stands next to clearcutting as a simple and easy method to practice.

4. As contrasted to clearcutting with natural reproduction, it provides better control of the species in the reproduction on the cutover area, since only individuals of species which it is desired to reproduce are left for seed trees.

5. Since a supply of seed is provided on every acre (and dependence is not placed as in clearcutting upon seed disseminated from the side of the clearing), large areas can be cut over at one operation with adequate provision for restocking. A second cut on the area to remove the seed trees is not necessary unless it proves to be financially profitable. Under conditions permitting only extensive management this advantage may be of primary importance.

Disadvantages. 1. By virtual clearing of the area, it induces conditions which for most species are adverse to the growth of seedlings and render establishment of a satisfactory reproduction uncertain (see under Chapter IV, "Disadvantages, 1" for further details). In the seed-tree method exposure of the ground takes place to a degree only slightly less than in clearcutting, with similar disadvantages.

2. It affords relatively poor protection against erosion, landslides, snowslides, and rapid runoff of water.

3. While esthetically it is preferable to clearcutting, it does not commend itself from the standpoint of forest esthetics as compared with shelterwood and selection.

4. On account of the danger from wind in which isolated trees are placed, it is applicable only with comparatively deep-rooted species. In stands which have been properly tended from youth, and in particular have been systematically thinned over a period of years, trees can be developed into stocky, deep-crowned individuals which will stand as seed trees even though the species may not by habit be deep rooted.

5. It is restricted to species which have light wind-disseminated seeds capable of germinating on clearings and developing thrifty seedlings under such circumstances.

6. The supply of seed is relatively scanty, compared with that available in the shelterwood and selection methods, coming as it does from a few seed trees.

7. As contrasted to clearcutting it is not applicable in stands of overmature timber. The individual trees, owing to their large size and age, are not well suited to be left as seed trees, unless enough cull trees can safely be used for the purpose.

The disadvantages with the exception of items 4 and 7 are overcome to some extent by the reserve-seed method.

Application of the Method. The seed-tree method should find frequent and successful use in forest regions where climate favors natural reproduction. In regions where natural reproduction is seriously handicapped by adverse climatic factors the seed-tree method with its scanty seed supply and exposure of the ground is out of place.

Since the seed-tree method can be applied with only one cutting which removes nearly all the timber but provides for restocking, it may prove valuable where methods requiring more cuttings are too expensive.

Several of the southern pines, including longleaf, loblolly, and

slash pines, can be easily reproduced by this method. Investigations made by Cope (1923 and 1924) first demonstrated this in loblolly pine stands. He advised leaving 4 seed trees per acre or about 700 feet, board measure. An essential feature is creation of the required seedbed condition, namely a bare soil. This is accomplished by burning over the area either before or after logging. Burning after logging consumes the slash. However it may destroy the current seed crop if that has fallen before the logging. Loblolly seeds abundantly at intervals of 2 to 4 years. If preferred the soil can be exposed by breaking up the litter with a plow or by raking it up for bedding. In an experiment reported by Cope a stand of 1700 seedlings per acre, 1, 2, or 3 years old, was secured on an area that had been burned over 3 years before, the seed coming after the fire from scattered seed trees. The 2- and 3-year-old seedlings averaged respectively 1½ and 3 feet in height and would require no release in order to dominate associated hardwood sprouts and seedlings.

Haig, Davis, and Weidman (1941) consider the scattered-seed-tree method one of the several satisfactory ways of reproducing western white pine, particularly in evenaged stands of mature but not decadent timber. Experience has shown that western white pine seed trees standing alone are fairly windfirm and that the species establishes itself well on open areas, except on the more severe sites such as south slopes and exposed flats. The method should be used only on the less-exposed sites, leaving 2 to 6 western white pine seed trees per acre, about 10 per cent of the total volume. These trees should be 16 or more inches in diameter, breast high, and they should be vigorous individuals of the dominant- or codominant-crown classes. Usually it is impracticable to relog the area for the seed trees. To open the area adequately associated species must be cut as heavily as market conditions permit and defective and otherwise unmerchantable western hemlock and grand fir must be destroyed by girdling or by felling, piling, and burning. Davis (1942, p. 19) gives the cost of applying the scattered-seed-tree method at $66.80 per acre, of which $24.50 goes for piling and burning slash, $28.00 for disposal of unmerchantable trees, and $14.30 for loss in value of seed trees salvaged 10 years after cutting. It is a more expensive method for regenerating western white pine than either clearcutting and planting or clearcutting in alternate strips.

The scattered-seed-tree method was followed in certain stands of white and red pine now included in the Minnesota National Forest. This timber was evenaged old growth and as such not suited for reproduction by the seed-tree method. Too few seed trees were left

(owing to legal restrictions), and many of those remaining were poorly distributed. Cultural operations for the establishment and development of reproduction were neglected. In spite of these handicaps most of the area provided with seed trees of red pine eventually became stocked with reproduction. White pine has not been reproduced from scattered seed trees as successfully as red pine.

Scattered seed trees are sometimes used to restock cutover areas in the Douglas-fir types of western Oregon and Washington (Anonymous 1937). The method is employed in stands of overmature timber with many defective trees. Where these trees are unmerchantable they provide a cheap means of obtaining reproduction. At least 2 trees per acre and preferably more should be left, as mortality in such seed trees is very high (64 per cent in 8 years in one experiment).

Among broadleaved species yellowpoplar is an example of a species well adapted for regeneration by the scattered-seed-tree method. Its seed is easily disseminated by wind, and good seed crops may be expected annually (McCarthy 1933, p. 44). Seedlings develop well in full light on clearings located on the better grade of sites suited to the species. Since yellowpoplar is one of the most desirable species to grow in the mixed stands where it occurs, the objective of management is usually an increase in the proportion of yellowpoplar. This can be accomplished by clearcutting leaving from 1 to 5 seed trees per acre, depending upon the size of the trees. It is only in second-growth stands cut around 40 years of age that the larger number of seed trees would be needed. Since yellowpoplar seedlings often have to meet severe competition from fast-growing sprouts of inferior species, a cleaning is likely to be required to establish yellowpoplar in a dominant position.

The State of Louisiana in 1922 passed a law requiring the leaving of an average of 1 seed tree per acre on cutover pine lands. In 1926 this law was changed to provide 2 unbled seed trees per acre for each 10-acre area. A seed tree must be not less than 10 inches in diameter breast high. Since the southern pines reproduce well from scattered seed trees, this law is theoretically in harmony with good silvicultural practice for the pine type. As regards details it does not provide, on the average, for an adequate number of large enough trees to obtain full restocking of the area quickly. Details of silvicultural practice should not be prescribed by law.

In 1940 the State of Virginia enacted a law requiring, within certain counties in eastern Virginia, the leaving of loblolly and shortleaf pine seed trees after cuttings in stands predominantly pine. This law requires 3 pine trees to be left per acre if the diameter outside

the bark at one foot above ground is 10 inches and 4 pine trees if it is 9 inches. The trees left must be healthy, windfirm, of well-developed crown, and evidencing seed-bearing ability by the presence of cones in the crown. The seed trees must not be cut for 10 years. This is another example of a well-meaning but ineffective effort to obtain desirable silvicultural results by legislation. Three to four trees per acre of these small sizes are too few to produce within 10 years enough seed to restock the cutover area adequately.

A seed-tree law was enacted by the State of New Hampshire in 1921, providing that at least one 10-inch, windfirm pine of good crown spread should be left on each acre cut in the eastern white pine type. The scattered-seed-tree method is not suitable for white pine in New England. Hence good results in the way of pine reproduction could not be expected, unless much more timber than required by this law was left. The law has never been enforced.

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CHAPTER VI

THE SHELTERWOOD METHOD

Definition. The principle of the shelterwood method involves the removal of the stand by a series of partial cuttings, resembling thinnings, that remove the entire stand within a period of years which is a small fraction of the rotation age. Natural reproduction starts under the protection of the older stand and is finally released from this shade and protection when able to endure the exposure. It is a logical further development of the seed-tree method retaining large numbers of seed trees instead of a few.

The terms "progressive fellings," "stand," "uniform," and "compartment" have been used to describe the shelterwood method.

Form of Forest Produced. The shelterwood method is best applied in evenaged stands, though it can be used in those of irregular form where merchantable age classes predominate. It produces an evenaged stand, thus resembling the clearcutting and seed-tree methods. In some cases the reproduction cuttings may extend (when the rotation is long) over a period of 40 to 60 years, which tends to create a wider range in the ages of the individual trees than the other two methods. Usually the regeneration period will be not less than 10 or more than 20 years. Even with a long regeneration period the stand still remains essentially evenaged.

Details of the Method. In the shelterwood method, as its name implies, reproduction is secured under the shelter of a portion of the old stand. Besides furnishing the seed, the old stand affords protection to the young seedlings. A time finally comes when this shelter instead of being a benefit is a hindrance to the growth of the seedlings. It becomes necessary to remove the remainder of the old stand, giving the new stand possession of the area and opportunity to develop in the evenaged form.

The whole process, including the securing of natural reproduction, its protection, and its final release from shelter, is accomplished within a relatively short period.

A minimum of 2 cuttings is required in the simplest application of the shelterwood method. Under intensive management several cuttings, often exceeding 10 in number, are made in the gradual process of simultaneously freeing the reproduction and removing the

mature stand. The cuttings may be classed under three heads:

1. Preparatory cuttings which prepare for reproduction.
2. Seed cuttings which assist in establishment of the reproduction.
3. Removal cuttings which aid the development of the seedlings.

The detailed application of the method can best be presented by taking up each of these cuttings in turn.

Preparatory Cuttings. If natural reproduction is to start under the old stand a supply of seed must be available and site conditions must be favorable for germination of seed and establishment of seedlings.

With the entire stand available as a source of seed supply there should be an abundance of seed for restocking the area. In very dense stands where the best individual trees possess short, narrow crowns and are poor seed producers, preparatory cuttings may be needed to encourage an enlargement of the crowns, to assist assimilation, and as a consequence to stimulate an increased production of seed. Ordinarily preparatory cuttings are not needed for this purpose.

Their principal function is to create ideal site conditions for the germination of seed. In closed stands there may be too thick and dry a forest floor for seedlings to get their roots down into the soil. Decomposition of the litter can be hastened by admitting, through cutting, more light, heat, and free circulation of air. This is accomplished by the preparatory cutting. Too rapid and complete disintegration of the humus is possible and may allow grass and weeds to spring up. The right condition of seedbed for each species must be known and the severity of the preparatory cutting governed accordingly. (See Figs. 15 and 16.)

When the mineral soil appears in spots here and there and small patches of grass and herbs start, then ordinarily the litter is sufficiently decomposed. Where the humus layer is of the mull type the surface soil is already in excellent condition for the germination of seed and preparatory cuttings for the purpose of improving the seedbed are unnecessary.

A minor object of the preparatory cutting may be to develop windfirm trees which can safely be left isolated in the later cuttings. This is especially necessary in dense stands where the crown development of the individual trees is poor.

In dense stands it requires from 3 to 10 years to accomplish the results for which the preparatory cuttings are made.

Often no preparatory cuttings at all are demanded, particularly

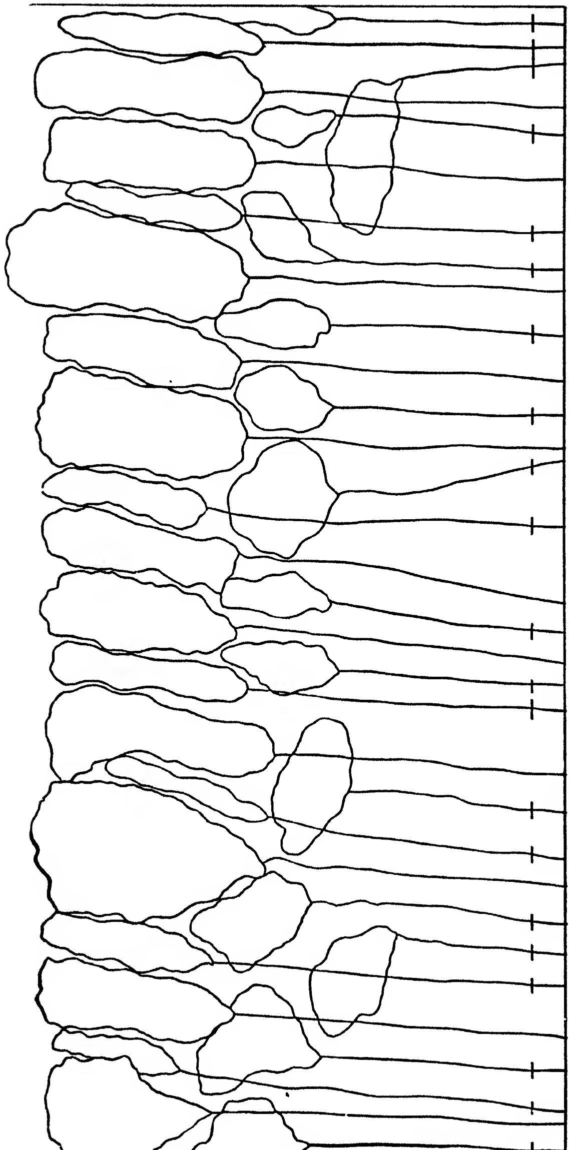


Fig. 15.

Hardwood stand, to be reproduced by the shelterwood method, marked for the preparatory cutting. Trees to be removed are indicated by dashes.

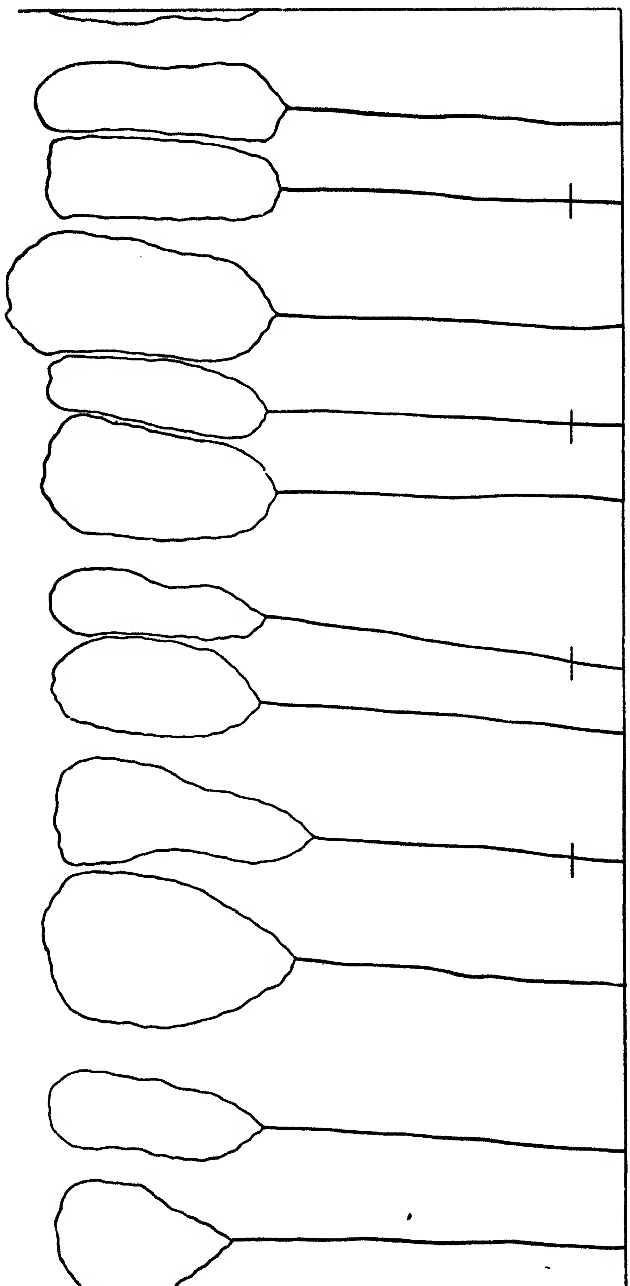


Fig. 16.

Same stand as in Figure 15, but three years after the preparatory cutting has been made. The trees to be removed in a seed cutting are marked.

in stands that have been systematically thinned previous to the reproduction period. The repeated thinnings improve the crown development of the trees and hence their seed-producing ability. Decomposition of the litter proceeds more rapidly in the thinned stand. In fact reproduction in many types may begin to appear as a result of thinnings even before reproduction cuttings are initiated (Leffelman and Hawley 1925, pp. 5–6). For these reasons preparatory cuttings are superfluous in stands where thinnings have been made.

When preparatory cuttings are required they may range in number from one to several. The number of cuttings depends on the length of time required to accomplish the purposes for which they are made and upon the necessity for only gradually making openings in a given stand.

The trees cut in preparatory cuttings should be selected from overtopped and intermediate trees. These are the classes from which the greater number of trees selected normally should come. In addition should there be diseased or defective trees it is best that they be removed, since such individuals will not be wanted as seed trees. Finally, if more opening is wanted to accomplish the purposes of the preparatory cutting, selections may be made from individuals of undesirable species and from trees with overdeveloped and spreading crowns.

This leaves principally dominant and codominant trees. Ordinarily it is impossible to remove all the trees which might be selected for cutting without taking out a greater proportion of the stand than is warranted for accomplishing the purpose of the preparatory cuttings. Hence some of them must be left until later cuttings. The trees left should be so spaced as to provide an even crown cover over the area preferably with spaces not more than 3 to 5 feet in width between the edges of the crowns. In volume from 10 to 30 per cent of the stand should be cut in the preparatory cuttings.

Seed Cutting. The purpose of the seed cutting (of which there should be only one) is to establish reproduction. The seedbed has been brought into excellent condition for the start of young seedlings. A seed year is awaited, and when it arrives a cutting is made, preferably just after the seed has matured. The logging serves to work the seed thoroughly into the thin humus and mineral soil. It finds here an ideal germinating bed with an abundance of light and heat made available as a consequence of the reduction in the forest cover. If a mellow seedbed has been created and a plentiful supply of seed deposited upon it and mixed with the soil, a complete repro-

duction may be secured immediately. Unfortunately such an ideal combination is difficult of attainment. The seed cutting should never be made until a good seed year occurs. If this requirement is scrupulously adhered to the chances for a successful regeneration are excellent.

If it is apparent that the thinnings or the preparatory cutting have failed to create the proper seedbed conditions they may be produced artificially. Such methods as preparing seed spots at close intervals, plowing furrows under the trees, or turning in hogs to work up the soil and humus may be employed. For details as to the kind of treatment required see the section entitled "Preparation of the Cut-over Area Preliminary to the Establishment of Reproduction," given under "Clearcutting with Natural Reproduction" but applying also to the shelterwood method.

As yet in applying the shelterwood system under American conditions expensive soil preparation and artificial restocking of failed places rarely have been undertaken. Action of this sort has been only a last resort when it was seen that natural seeding had proved a failure. It has already become apparent, even with many of the species well suited to the shelterwood method, that soil preparation and the elimination of competing vegetation are essential operations that cannot be neglected. This is particularly true in mixed stands and in reproducing temporary forest types.

The trees selected for removal in the seed cutting are of the same general classes as those taken in the preparatory cuttings. Should it be necessary to take out more trees than those designated for removal in preparatory cuttings, the poorer individuals in the codominant and dominant classes are cut. Especially should trees with spreading crowns be removed since such individuals intercept rain, warmth, and light and will cause the greatest injury to young growth when removed in a later cutting.

The severity of the seed cutting is governed by the distance to which seed may be distributed (with heavy-seeded species) and by the amount of shade which it is necessary to maintain in order to assist germination and to protect seedlings from drought, frost, and rank growths of grass and herbs. Inasmuch as the balance of the stand must be removed after reproduction is started and with considerable injury to the seedlings, it is advantageous to take off as much of the old stand as possible in the seed cutting. The amount removed should be from 25 to 50 per cent of the volume of the original stand before preparatory cuttings were begun.

It is not necessary that the distribution of the trees left be abso-

lutely uniform, although reasonable uniformity is attempted. In fact an uneven distribution, provided the open areas among the old timber are kept small, may not be unfavorable to the seedlings in their competition with the older trees for soil moisture. In the seed cutting advantage is taken of all groups of advance growth, which may have started accidentally or as an unlooked-for result of the preparatory cuttings or thinnings. Over such groups the cutting is heavy and may even remove all the old timber. In fact it is possible to find stands in which reproduction has started so well as a result of systematic thinning that neither preparatory nor seed cuttings are needed. Here the first reproduction cutting will be a removal cutting.

Usually 3 to 5 years elapse before the seed cutting is followed by a removal cutting.

Removal Cuttings. Removal cuttings have as their object the gradual uncovering of the new crop which finally is given complete possession of the area. There may be one or, in intensive management, several removal cuttings, the last of which is called the final cutting. The severity of the removal cuttings and the intervals at which one follows the other are governed by the degree to which the young stand needs protection or is suffering from too much shelter.

After the reproduction is established it is watched for indications of poor condition. Such points especially as unhealthy color of the foliage, falling off of height growth and bending aside toward the light are taken as showing the need of less shade and competition. This condition of the reproduction is not likely to be found uniformly over the whole area at any one time. On the contrary a patch here and a patch there will probably require treatment. Hence the removal cuttings are not made evenly over the whole area. A group may be cut clear in one place and a few trees thinned out in other places; elsewhere there may be no cutting. A few years later a similar cutting will be needed, and the process continues until at last all the old timber is harvested. (See Fig. 17.)

Removal cuttings are likely to be needed at intervals of 2 to 5 years and to cover a period of 2 to 20 years. They utilize the remaining 25 to 50 per cent of the volume of the original stand.

Each removal cutting does some injury to the young stand. Where proper methods are enforced in felling trees and in hauling the logs to the roads this injury is not of serious consequence. Hauling out the logs with single horses makes narrow lanes through the reproduction and minimizes the damage from this source. Even though the trees in being felled will destroy many seedlings, this loss will rarely interfere with a full stocking of the area.

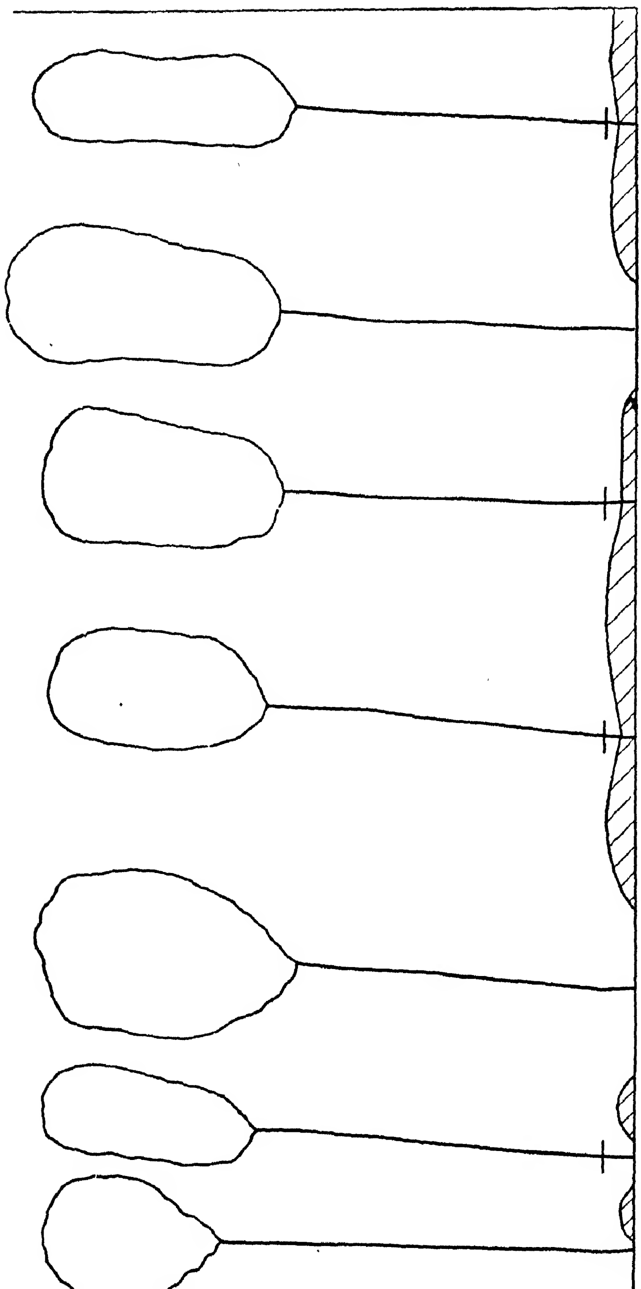


FIG. 17.

Same stand as in Figures 15 and 16, but five years after the seed cutting has been made. Note that reproduction (indicated by cross-hatching) has started and is developing under the old stand. Trees to be cut in a first removal cutting are marked with dashes.

Modifications of the Method. Under present conditions the shelterwood method is rarely applied with the full details as described in the preceding pages. Many modified methods are in use, all of which may be divided into the following classes on the basis of their application in the stand:

1. Application uniformly over the entire area — the uniform method.
2. Application in strips — strip shelterwood.
3. Application in groups — group method.

The details as already described relate particularly to the uniform application of the method although in the strip and group modifications the principle is essentially the same except that a given cutting is extended over a portion only, instead of over the entire stand.

Strip-Shelterwood Method. In this modification of the shelterwood method the stand, instead of being treated uniformly throughout its whole area, is worked in strips, the cutting at any given time being concentrated within certain strips and the other portions of the stand remaining temporarily untouched.

The difference in arrangement of the cuttings is illustrated in Figures 18 and 19 where the uniform and strip methods are compared by diagrams.

Starting on one side of the stand the first strip receives either a preparatory cutting, if needed, or, more probably, a seed cutting. After a few years another cutting, probably a removal cutting, is made on the first strip while the adjoining strip receives a seed cutting. A few years later the first strip may receive a final cutting, the second strip a removal cutting, and the third strip a seed cutting. In this manner (see Fig. 19), the series of cuttings progress strip by strip across the stand. The strips should be kept narrow, preferably not over twice as much as the height of the mature timber, for otherwise the inherent characteristics of a strip-shelterwood cutting are lost.

Several other ways of executing the cuttings may be used in applying strip shelterwood besides the one shown in Figure 19. For example, the first reproduction cutting made may be the clearcutting of a long, very narrow strip, only 10 to 25 feet in width. From this as a starting line, progressively lighter cuttings are extended for a short distance into the stand. Here may be found examples of preparatory, seed, removal, and final cuttings, but each on such a narrow zone and so intimately associated with the other as to be scarcely distinguishable. This strip, approximately 100 feet in width

from the closed forest on one side to the edge of the clearing on the other, is advanced slowly across the stand, just as fast as the repro-

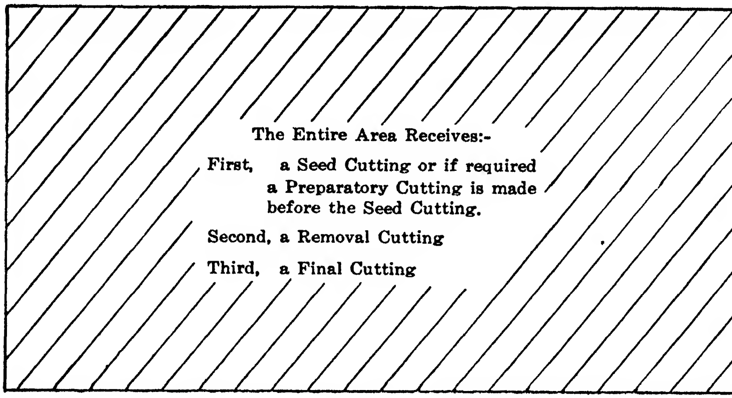


FIG. 18.

Diagram of a stand reproduced by the shelterwood method, each cutting being applied uniformly to the entire area. Compare with Figures 19 to 22. The preparatory cutting is usually unnecessary.

duction becomes established and capable of being completely uncovered. The strip may advance from 6 to 25 feet per year. This

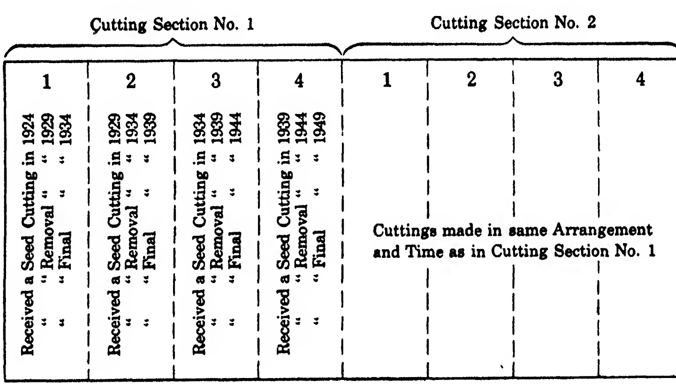


FIG. 19.

Diagram of a stand reproduced by the strip-shelterwood method. Two cutting sections are used. The period of regeneration is about 25 years in length and the stand is kept in the evenaged form. A preparatory cutting in most cases is unnecessary and hence is omitted from the diagram.

method was developed by Wagner (1923) in the management of a forest, composed principally of Norway spruce, located at Gaildorf in Württemberg.

It is not necessary that the edge of this strip be straight. An

irregular or undulating line may be advantageous in exposing a longer frontage to regeneration and thus hastening the advance of the strip.

There appear to be several advantages of the strip arrangement over the uniform application. Better protection is afforded against windfall since part of the stand is kept intact as a windbreak and no considerable areas on which the trees occur isolated are left at any one time. Better or quicker reproduction should be secured because of the extra amount of seed furnished by the trees on the adjoining strip which is less heavily cut, and because the side shade and protection against evaporation afforded by this strip should conserve the soil moisture.

The wider range of conditions for reproduction afforded on the narrow strips should result in a mixture of species in the new crop. Trees which must reproduce under conditions of heavy shade can find their optimum on the inside edge of the strip. Species preferring full overhead light for reproduction may find it just outside the edge of the old timber. The portion of the stand which has recently received the final cutting is still within reach of numerous seed trees and may continue for several years to restock with seedlings. Damage to reproduction from the removal of the mature timber can be kept at a minimum, since there is better opportunity in strip cuttings to remove the trees cut through the uncut portions of the stand instead of always over the area being reproduced, as must be done in the uniform application.

The initial location and direction of progress of the strips must receive careful consideration in all strip methods. In general the strips should be so arranged as to advance in the direction that affords the best protection to the reproduction. This ordinarily will require an advance either in the direction of the sun (that is from the north toward the south) or in the direction from which comes the most dangerous wind. Which of the factors is of primary importance will depend on the local requirements of the species. In some instances reproduction may start best on the side of a stand protected from the sun; in others the direct rays of the sun may be needed for satisfactory reproduction.

The topography will influence the arrangement of the strips. On slopes the strips preferably should advance from the top downward, thus allowing the timber to be taken out downhill and not through the area being reproduced. Where needed protection can be secured by so doing, the strips may be run from the top to the bottom of the slope and advance along the sidehill.

The length of the period of regeneration is the same as under the uniform application of the method. If the strips are narrow and the stand is a large one, it will be necessary to establish several cutting sections in order to complete the reproduction cuttings within the allotted period.

Strip shelterwood does not necessarily cause any greater range of age between the individuals of the new stand than does application uniformly over the entire area, since the period of regeneration is the same in the two cases. The differences in age are not noticeable, although the average ages of the trees on the strips first operated are greater than those on the strips in which cuttings start later. The total range of ages is so small as not to interfere with the evenaged character of the stand.

Group Method. Commonly in evenaged forests, particularly in those which have undergone thinning or had their regularity disturbed by natural agencies such as wind, insects, or fungi, it happens that, when the beginning of the period of regeneration is reached, groups of advance reproduction are already present. The groups may range from a few trees to considerable areas of young growth and from seedlings a few years old up to trees of sapling size.

Where this condition exists the reproduction cuttings are made, not uniformly over the area but irregularly and entirely with reference to the special requirements of each group of advance reproduction. The first cutting made combines removal cuttings (including the final cutting), seed cuttings, and preparatory cuttings all in the one operation. Where the advance reproduction is largest the cutting removes all the old trees and is thus a final cutting. Where reproduction shows indications of too severe competition with the overwood, but is not yet capable of being left without some protection, a removal cutting taking part of the old timber is made. Where reproduction has not started as yet, but seedbed conditions are suitable for its establishment, a seed cutting is executed. Finally, if any cutting at all is made in the denser portions of the stand, it will be in the nature of a preparatory cutting. Ordinarily each group of advance reproduction serves as a center from which the cutting radiates. Over the higher reproduction at the center of the group a final cutting is made. In a belt surrounding this center, removal cuttings are made decreasing in severity as the younger reproduction toward the edges of the group is reached. In a belt encircling the group of reproduction a seed cutting takes place, while beyond this area a ring of forest receives a preparatory cutting. Beyond this ring the forest remains untouched.

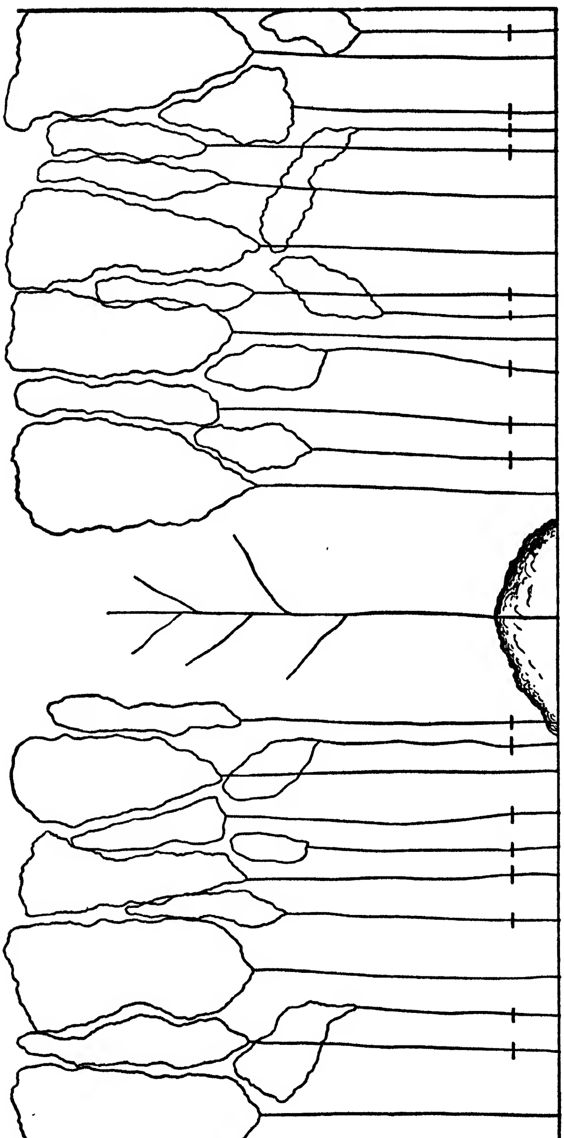


FIG. 20.

The group method. A portion of a hardwood stand is shown marked for the first cutting. The patch of advance reproduction serves as the center for starting one of the groups. The trees to be removed are marked by dashes.

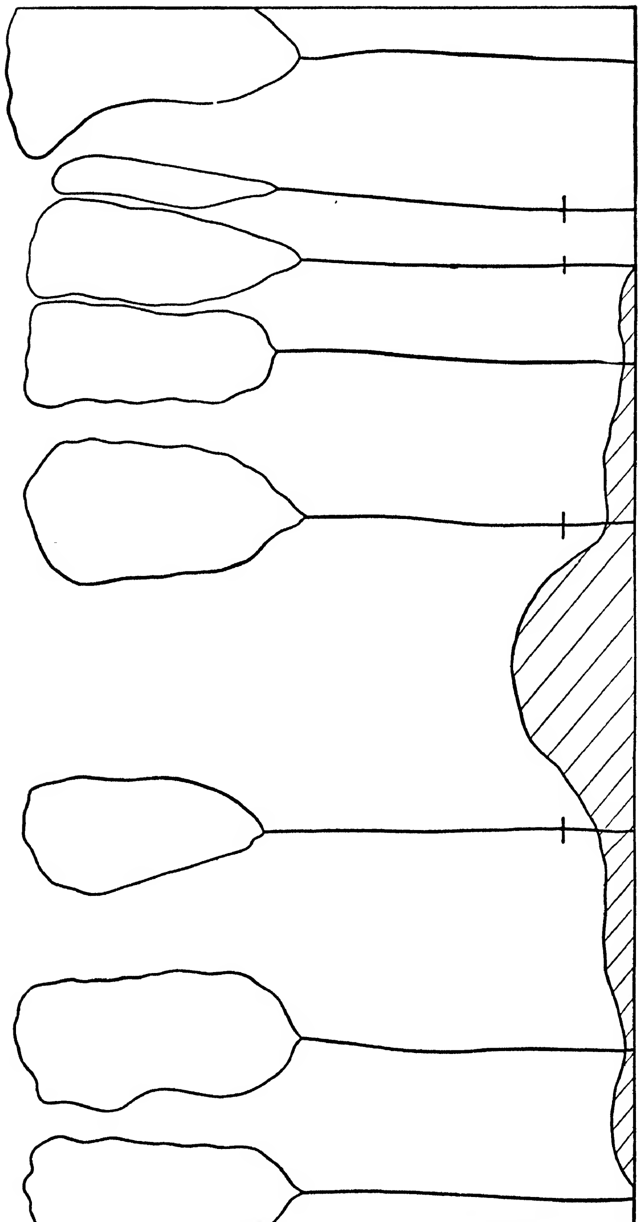
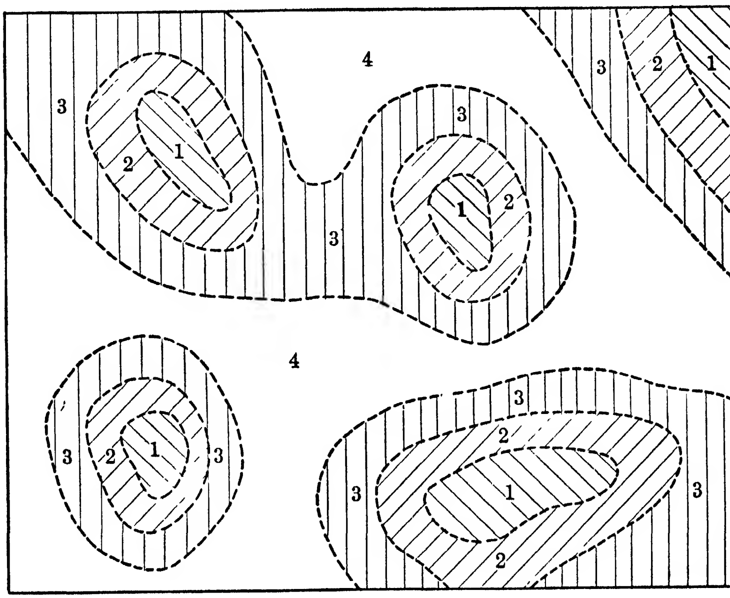


Fig. 21.

Same stand as in Figure 20, but five years after the primary cutting. Now marked for another cutting. Reproduction is shown by cross-hatching.

After a few years when conditions indicate its desirability, another cutting is made of the same type as the primary cutting, uncovering additional areas of reproduction and extending the removal, seed, and preparatory cuttings over additional territory (see Figs. 20 and 21). At intervals additional successive cuttings are made steadily broadening the area cut over until finally the various groups which served.



Character of Cutting	Areas Marked:-			
	1	2	3	4
	Received Cuttings in Years as follows:-			
Preparatory and Seed Cutting combined		1905	1910	1915
Removal Cutting		1910	1915	1920
Final Cutting	1905	1915	1920	1925

FIG. 22.

Arrangement of the cuttings in a stand reproduced by the group shelterwood method. Advance reproduction was present on areas marked "1" before the cutting.

as original starting points are expanded until they merge and the entire stand is reproduced (see Fig. 22).

After the groups of advance growth are well established and somewhat enlarged, it often may be better practice to remove the rest of the stand gradually in the form of an advancing strip than to widen each group until they all merge. Extraction of the timber will be easier with a minimum of injury to the reproduction where the advancing strip method is employed.

In stands not containing enough clumps of advance reproduction to furnish sufficient starting points for the first cutting, small openings may be arbitrarily created to encourage reproduction and to serve as initial points for further extension of the group cuttings.

The period allotted to reproduction cuttings under the group method may be of the same length as that used in uniform and strip shelterwood, but, since advance reproduction (often 20 to 30 years old) is already present when reproduction cuttings commence, the range in age between individual trees of the new stand is apt to be wider than in the other two methods. Generally the stand can still be classed as evenaged.

The group method, when employed on a long rotation with a correspondingly long period of regeneration, produces a forest of about the same form as the selection method, as will be better understood after consideration of the chapter on selection.

The group method is excellent for reproducing shade-enduring species and not so good as strip shelterwood for light-demanding trees. One disadvantage of the group method as compared to the uniform or strip shelterwood methods is that with species sensitive to frost excessive localized injury may result. This occurs because frost pockets are likely to be caused by the merging of the groups of reproduction. These groups slope down from their highest points to low spots where the seedlings started last or are still missing. In these closed basins or frost pockets it is very difficult to obtain a satisfactory stand of young trees and grow it to a height safe from frost.

For really satisfactory results, the group method requires close attention by a skillful staff because of the scattered distribution of the areas under regeneration and the necessity for individual treatment of each group. There is likely to be more injury to reproduction from removal of the old timber in the group than in the strip-shelterwood method, because of the more irregular way in which old timber is intermingled with young growth.

Extensive versus Intensive Application. The discussion of the shelterwood method has up to this point related particularly to its intensive application.

Shelterwood, requiring as it does several cuttings on the same area within a relatively short period, inherently is best adapted for employment under conditions allowing intensive management. Only in regions where the market allows sale of lower-grade products such as cordwood, and where a permanent road system exists that permits easy access to all parts of the forest, can the shelterwood method be applied intensively.

The method meets so well the silvical requirements for reproduction of many important species that modifications to permit its application in an extensive way under poor market conditions and in the absence of permanent roads have been developed.

Summarized, these modifications consist in:

Reducing the total number of cuttings to two or three.
Lengthening the period between cuttings.
Omitting all refinements for securing a complete restocking.

Under extensive application no preparatory cuttings or thinnings are made. Instead of such cuttings the natural opening up of the stand with old age or by accidental factors is relied upon to produce seedbed conditions favorable to the start of reproduction. In some instances cuttings are deferred until considerable reproduction is already established under the original overmature stand, and in this situation no seed cutting is required.

Nature then frequently accomplishes the purpose of the preparatory and seed cuttings and enables the forester to commence his work with the removal cuttings. This fact furnishes one of the reasons why the shelterwood method may be so often successfully applied in an extensive manner. Opportunities for its use occur principally in stands of virgin timber which are opening up and deteriorating.

It is not necessary that reproduction be already on the ground when the first cutting is made or that the best conditions exist for the start of reproduction. The first cutting will have for its purpose the partial uncovering of reproduction already established and the establishment of reproduction on areas not yet stocked. Though partaking of the nature both of a seed cutting and of a removal cutting it may be termed a seed cutting. Forty to seventy-five per cent of the volume is taken out. The trees cut are those of the general type that would be selected for removal in the preparatory and seed cuttings of the method when applied intensively.

The virgin stands in which extensive application most frequently takes place usually contain a large percentage of defective trees. Frequently the problem in the first cutting is to find enough trees which can be profitably left until the next cutting to preserve the desired forest conditions. Good health, windfirmness, capacity for seed production, favorable location with respect to areas which require restocking or groups of reproduction which need shelter, and the length of time before the second cut govern the selection of the trees to be retained. Ten to fifty years after the seed cutting the final cutting is made, taking out all the remaining trees of the old

stand, completing the reproduction cuttings, and producing an approximately evenaged stand. A 50-year interval between the two cuts is altogether too long for the best silvicultural results, even on as long a rotation as 200 years. Much injury to the young growth is inevitable when the final cutting is delayed so long after the first cutting. Wherever market and logging conditions permit, the final cutting should follow the first within 20 years.

Preparation of the soil, removal of underbrush, and similar measures that might improve seedbed conditions and opportunities for the establishment of a more valuable reproduction are usually impracticable in extensive application of the shelterwood method.

Advantages and Disadvantages of the Shelterwood Method. *Advantages.* 1. Heavy-seeded species whose seeds are distributed principally by gravity can be successfully reproduced as well as light-seeded species. It thus stands in contrast to the clearcutting and seed-tree methods under which it is difficult if not impossible to secure adequate dissemination of heavy seeds.

2. Reproduction is more complete and certain than under the other methods of high forest which produce evenaged stands (the clearcutting and seed-tree methods). This is partly due to the greater number of seed trees that are present during the time reproduction is being established, which result in larger crops of seed being produced and being made available on all parts of the area. Better protection to the seedlings from frost and such desiccating agencies as sun and wind also aids in securing more certain and complete regeneration.

3. It is exceeded only by selection in its protective value. The ground is never bare of a forest cover. Even during the period of regeneration the old stand furnishes protection, until reproduction is fully established, against erosion, landslides, snowslides, and rapid runoff of water. Excessive growths of grass and herbaceous cover can be kept in check, while seedlings are sheltered from the drying influence of sun and wind and from injury by frost. Less injury from insects to young trees may be anticipated than where reproduction takes place on clearings.

4. Though inferior to selection in the maintenance of esthetic effects it is superior to all other high-forest methods producing evenaged stands. This is particularly noticeable during the period of regeneration, when forests treated under the clearcutting and seed-tree methods do not present an attractive appearance.

5. Since it is the only high-forest method producing evenaged stands which furnishes shade and shelter to seedlings, it is the best method to use with species which can be reproduced naturally *only*

under such conditions and for which evenaged stands are desired.

6. In production of wood material, the forests may show better results than those managed under the clearcutting or seed-tree methods. This will not be universally true. Under unfavorable climatic conditions and with infertile soils shelterwood because of the better protection afforded should give higher production. Although young plants, not held back by overhead cover, grow fast in youth on clearcut areas, yet the reproduction raised under shelter begins its development before the last of the old timber is harvested and therefore has a start over that originating after clearcutting. During the regeneration period the mature timber left in relatively open position as shelter to the reproduction is enabled to put on a high increment. On fertile soils with abundant and timely precipitation there may be no measurable difference in production between clearcutting and shelterwood methods (Schlich 1924 and 1925).

The good points of shelterwood are well summarized in the following quotation from Trevor (1938, p. 317) in his discussion of silvicultural systems in British India. "The system can be applied in the hills and plains under all conditions where natural regeneration can be obtained at the will of the forester. The difficult silvicultural operations are well defined and not too difficult of execution, the concentrated nature of the regeneration renders supervision easy, and the more or less evenaged crops produce the best possible class of produce. Where grazing rights exist it is possible to close areas under regeneration to grazing or to fence them against game. The state and progress of regeneration is always manifest and not obscured as under the selection system, and the age-class distribution is satisfactory. The staff can see the results of their work and take a personal pride in their regeneration areas. The introduction of the uniform system has greatly improved Indian forestry."

Disadvantages. 1. It cannot be applied when there is great danger from windthrow or breakage since many trees stand isolated during the regeneration period. The danger may be minimized by preparatory cuttings and thinnings which tend to develop windfirm individuals. The inherent ability of the species to withstand windthrow and breakage as well as the relative exposure of the site to strong winds determine the importance of this disadvantage. With a species easily injured by wind or on much-exposed sites some other method besides shelterwood should be employed. If the method can be applied intensively, with numerous cuttings following one another at short intervals, considerable windfall need not interfere with its successful application. The damaged trees are salvaged at each

cutting. Should injury by wind affect a large portion of the old stand at any one time the results might be serious. In weighing the danger of windthrow and breakage as a disadvantage of the shelterwood method, the question of whether the mature trees damaged by wind can be salvaged is not the only consideration. The injury from drought and frost suffered by the young reproduction left exposed unexpectedly through the destruction of the sheltering old wood may be the most serious consequence.

2. It demands for intensive application economic conditions making profitable the removal of the stand in several cuttings. To justify such operations there must exist:

(*a*) A market for small and low-grade forest products (particularly cordwood and pulpwood).

(*b*) An organization of the logging so arranged that the same area can be operated at short intervals for a period of years necessary to establish reproduction. This increases the expense of logging, requiring, as it does, an extension of the time within which a specific amount of timber is taken from a given area and considerable care to preserve reproduction in felling and transporting trees from the felling area.

As explained under "Extensive versus Intensive Application," page 133, shelterwood, shorn of its refinements, can be used in a crude way under comparatively poor market conditions.

3. Greater technical skill is called for in applying it than in applying the clearcutting and seed-tree methods. Selection, when used with an equal degree of intensity calls for more technical skill.

4. Part of the reproduction is destroyed in the removal cuttings. Where reproduction is plentiful and the proper care is exercised, the inevitable destruction of some young trees in the logging will not reduce the reproduction below the point of full density. Careful work to keep damage to reproduction at a minimum tends to increase the expense of logging as previously stated.

Application of the Shelterwood Method. As yet the economic conditions permitting the intensive use of shelterwood are found in relatively few sections of the country. East of the Great Plains there are many districts where cordwood is salable and logging can be so arranged as to permit shelterwood cuttings. Numerous examples can be found on the small tracts typical of thickly settled districts. For parks and estates where esthetic effects are desired along with production of timber in evenaged stands, shelterwood should be chosen.

Many of the heavy-seeded hardwoods, particularly the oak family,

are species that can be best managed under shelterwood. To cite one example, a 27-acre 56-year-old stand, on the Eli Whitney Forest, New Haven, Conn., of mixed hardwoods chiefly oaks and red maple, understocked and frequently burned over by light surface fires, was taken under management in 1902 and shelterwood cuttings started. A preparatory cutting removing 9 cords of fuelwood per acre was made. In the period from 1906 to 1913 what amounted to seed cuttings were made in different parts of the stand, removing principally chestnut dying of the blight. About 11 cords per acre was taken out in this cutting. In 1921 the final shelterwood cutting was made, removing 4150 feet, board measure, per acre and an additional 13 cords per acre of fuelwood. Four years after this last cutting mixed hardwood reproduction ranging from 5000 to more than 15,000 stems per acre stocked the area, with a satisfactory proportion of seedlings of the more valuable oaks.

Downs and McQuilkin (1944) in a study of seed production of southern Appalachian oaks came to the conclusion that either a 2-cut shelterwood cutting or selective cutting by small groups is the method best suited for regenerating the oaks. The cover of leaves on the forest floor and the canopy of tree crowns protects the acorns. The trees remaining after the first cut are close enough together to disperse the heavy seed over the entire area. After the second cut which removes the remainder of the old timber, the open conditions so essential for favorable development of young oak stands are provided.

Species like red spruce, balsam fir, white ash, and eastern white pine, which under certain circumstances desire partial shade and protection for reproduction, can be successfully managed by the shelterwood method.

An illustration can be drawn from a 53-year-old stand of eastern white pine at Keene, N. H., growing on a gravelly sand of poor quality. A light cutting (preparatory) was made in 1900 followed by a heavy cutting (seed) in 1904 which left the crowns of the remaining trees a few feet apart. The year 1904 was a heavy seed year. In 1905 over 11,000 white pine seedlings per acre were present, nearly all from the 1904 seed crop. In 1909 seedlings up to 18 inches in height to the number of 4000 per acre still persisted under the shelter of the old stand. The remainder of the old stand was cut clear in the winter of 1912–1913. In 1915 there was an average stand of 1500 white pine seedlings per acre ranging up to 4 feet in height. The stand had been successfully reproduced by the shelterwood method. See also Dana (1930).

Shelterwood is more effective than other methods for western white pine on the more exposed sites where shelter is essential to secure establishment of natural regeneration (Haig, Davis, and Weidman 1941, pp. 88–90). The drawback to its use is that, until market conditions improve so that timber of associated species can be sold profitably, it is not practical to apply shelterwood. Another disadvantage is that more cultural work may be needed to bring the pine into dominant position since shade-enduring western hemlock and grand fir reproduce and develop well under shelter. However, the authors conclude that shelterwood is more generally desirable for western white pine than other applicable methods.

Rettig (1942), in describing cutting practices in western white pine stands on the Clearwater forest management unit of Potlatch Forests, Inc., advises the application of shelterwood cuttings in young timber of merchantable size and in stands of vigorous mature timber. As practiced in these stands, the first cutting removes about 60 per cent of the volume. The residual stand consists of white pines 17 inches or less in diameter, breast high, together with occasional larger pines and enough trees of other species to bring volume up to 40 per cent of the original. It is planned to return in 25 to 30 years for the second cut.

Shelterwood extensively applied, i.e., with 2 cuttings, is suitable for all stands, either evenaged or fairly regular in form, where the individual trees are mainly of merchantable size and condition but not all overmature. Throughout the western United States, where in many places conservation of soil moisture and protection from sun and wind are essential for the success of natural reproduction, a crude form of shelterwood can often be applied. The pure forests of ponderosa pine found in the Black Hills of South Dakota, and there characteristically more evenaged than is usual elsewhere for this species, are well adapted to shelterwood management. Natural reproduction in this region starts so abundantly under a partial (or even under a complete) cover as to make a 2-cutting shelterwood method successful.

Many ponderosa pine stands elsewhere in the West might be treated in a similar manner. The principal difficulty, under the economic conditions existing in the ponderosa pine regions, has been to make the second and final cutting soon enough after the first cutting for the best results to the young stand, much of which will die before it can be released by the second cutting. A 30- to 60-year interval may have to elapse between cuttings. This is too long for satisfactory application of the shelterwood method and in the past

has been one of the influences leading to adoption of the group selection method. If truck and tractor logging permits successive cuttings at intervals of 15 to 20 years, cuttings of the shelterwood type become feasible.

Present-day tendencies in cutting practice in ponderosa pine are toward selection types of cutting, discussed in the next chapter (page 172). In spite of this well recognized trend, it is likely that ponderosa pine, because of its silvical habits, will ultimately be managed under the shelterwood method.

Douglas-fir, Rocky Mountain variety, can be successfully reproduced by the shelterwood method. An experiment carried on in Colorado indicates that a 2-cutting method, with 12 to 15 years between the first and the final cuts, will result in establishing an excellent new stand of Douglas-fir (Roeser 1924). This investigation, which concerned the comparative amount and quality of the reproduction following clearcutting, selection, and shelterwood, demonstrated as a result of a 10-year observation that plants reproduced on the shelterwood area were superior in height and development to those of the same age on any of the other areas. The number per acre of established seedlings was greatest on the shelterwood area. Douglas-fir in the Rocky Mountains during the seedling stage needs the protection of overhead cover such as is furnished after the shelterwood type of cuttings.

Stoddard (1939) has shown the practicability and great advantage of changing the present method of destructive liquidation by clearcutting of old-growth hemlock-hardwood forests in the Lake States for a system of removing the old timber by a 2-cut shelterwood method, which provides for establishing a new crop. The forest, though not strictly evenaged, is composed principally of mature and overmature trees with some small trees, which may be looked upon as advance growth, and is sufficiently regular in form to lend itself well to shelterwood-type cutting. In the first cut approximately 60 per cent of the volume should be removed, taking out trees that have reached physical maturity, large overmature trees, medium-sized mature trees that are slowly ebbing, and smaller suppressed trees with little promise of future growth. The second cut follows in a short time (7 years later in the forests cited) and removes the remainder of the merchantable volume. After the second cut the area is left stocked with nearly 400 trees of the 2- to 8-inch diameter classes, together with reproduction that has come in since the first cut. It may be classed as a relatively evenaged stand.

As a general thing, neither the economic situation nor the silvicul-

tural condition of the stand justifies an intensive application of shelterwood in stands of old-growth timber. In such stands reproduction is likely to be present in greater or less amount, and the cuttings, if of the shelterwood type, may be begun in the removal-cutting stage. Old-growth timber is rarely found today located close to good markets and suited for intensive treatment.

Second-growth stands, younger, more regular, and made up of trees of smaller size than the virgin timber, offer better opportunities for management under the shelterwood method.

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CHAPTER VII

THE SELECTION METHOD

Definition. According to the principle of the selection method the oldest or largest trees in a stand are harvested. After one or more years similar cutting is made. This process is repeated at intervals throughout the rotation. The trees taken in a single cutting may occur singly or in small groups. A stand is never completely cleared off, but instead small openings are made here and there. After each cutting reproduction should start in the openings just created. The necessary seed and protection will be furnished by the trees standing around the openings. In connection with the harvesting of the oldest or largest trees intermediate cuttings may be made among the younger trees where needed to relieve competition.

Form of Forest Produced. From what has been said it is evident that cuttings under the selection method must produce an unevenaged form of forest. Such form is not a necessary condition for starting the method. Evenaged stands ordinarily contain trees of considerable range in diameter. By selecting at each cutting the largest (if not the oldest) trees, an evenaged stand may be reproduced under the selection method* and eventually converted into unevenaged form, if the first cuttings are light and are skillfully made.

A stand ideally suited to a selection method of cutting should contain trees of every age class from one-year seedlings to veterans of the rotation age. Such stands are not found in nature but are most nearly approximated in virgin forests. But usually in virgin forests (ordinarily considered all-aged) certain of the younger or middle-age classes are lacking or are not represented in the right proportion, and the stand is apt either to be composed of mature trees of about the same height and differing comparatively little in age or else to be of the two-storied character, each story being of practically the same age. In virgin stands of such species as spruce, the smaller trees often will be found on examination to differ relatively little in age from trees two to three times their size. With some shade-enduring

* An exception to this statement occurs where the smaller trees in an evenaged stand lack the power of recovery from their suppressed condition or are so small-crowned and spindling as to be windthrown or injured by sunscald or exposure.

species, like eastern hemlock, the virgin forest may contain a fairly intimate mixture of age classes, but with more light-demanding trees such as white pine the virgin forest is essentially evenaged (Hough 1932).

Where the virgin forest developed as a result of gradual successional changes, the variety of age classes is likely to be greater than when the virgin forest developed after a sudden catastrophe, such as extensive windthrow.

Since it is virtually impossible in nature to find all age classes represented in a single stand, a stand is considered all-aged or selection if a few broad age classes, each of 20- to 50-year range, are represented.

Details of the Method. In theory the oldest age class is cut each year, the next oldest in the following year, and so on indefinitely. Reproduction springs up in the openings immediately after cutting. By the time all the age classes in an all-aged stand have been cut over once, the seedlings started on the area occupied by the age class which was cut first will have matured. Thus in a true selection stand an old age class, consisting of scattered, single trees, ripe for cutting, will be available each year. (See Figs. 23 and 24.) The volume of this age class will be equivalent to the annual growth of the whole stand. Each age class should occupy its proper percentage of the area. For example, if there are a hundred age classes, each class should have one hundredth of the crown space allotted to it; and then if one hundredth of the area, in this instance, is each year actually cleared of trees or uncovered, only the trees belonging in the oldest age class will be removed. Since the trees making up the oldest age class are single, scattered individuals, it is necessary to work through the whole stand, and in fact through the whole forest, to find them and to conduct logging operations over the whole area each year.

In practice certain changes in this theory are demanded from both the logging and the silvicultural standpoints. The annual working of the whole area to secure a small cut per acre makes logging relatively expensive. Seed trees do not produce seed every year, and seedlings have difficulty in becoming firmly established when the area is cut over each year. To avoid these difficulties what is known as a cutting cycle is established. Under this scheme the entire forest is not cut over each year, but it is divided into as many portions as there are years in the cutting cycle. The cutting in a given year is restricted to one of these areas. Cuttings in successive years progress from one area to another and finally, after the cutting cycle is ended,

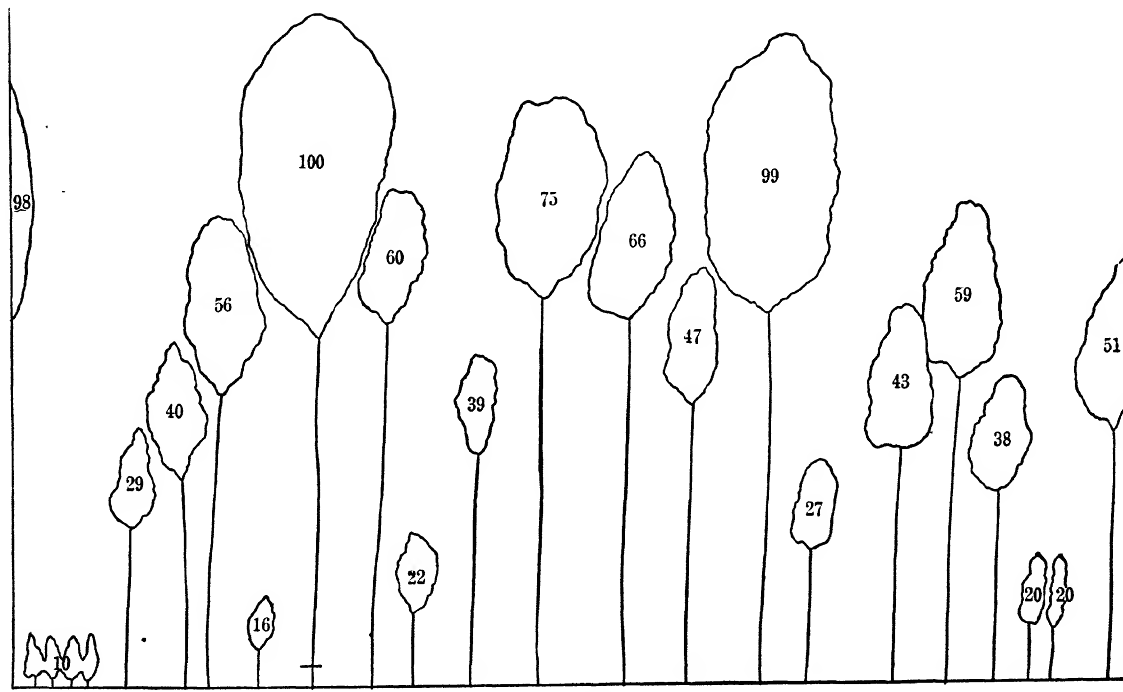

FIG. 23.

Portion of an ideal selection forest operated on an annual cutting cycle on a rotation of 100 years. The figures indicate the ages of the trees. Note that the 100-year-old tree is marked for cutting.

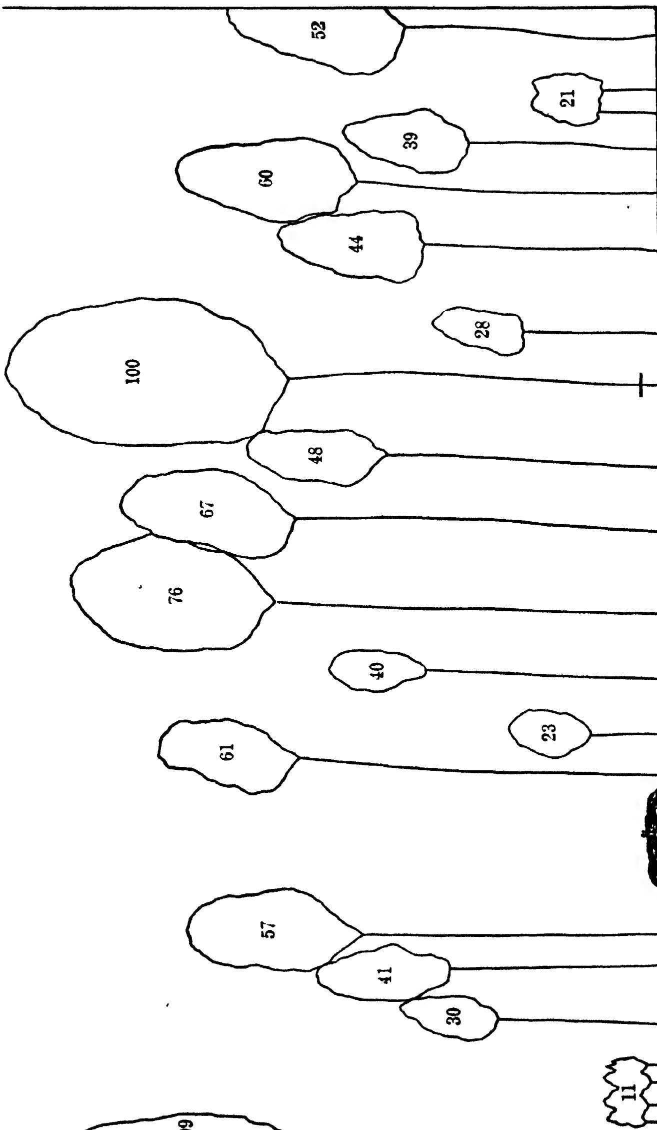

FIG. 24.

Same stand as in Figure 23, but one year later. Note that reproduction has started around the stump of the 100-year-old tree cut a year ago. The tree to be cut this year is marked. The figures indicate the ages of the trees.

return to the first area. The interval between cuts on a given area determines the length of the cutting cycle. In Europe the cutting cycle is likely to be less than 10 years; in the United States it may be 10 to 60 years.

Where the cutting cycle is longer than a year not every age will be represented in the stand, although every age class will be. There

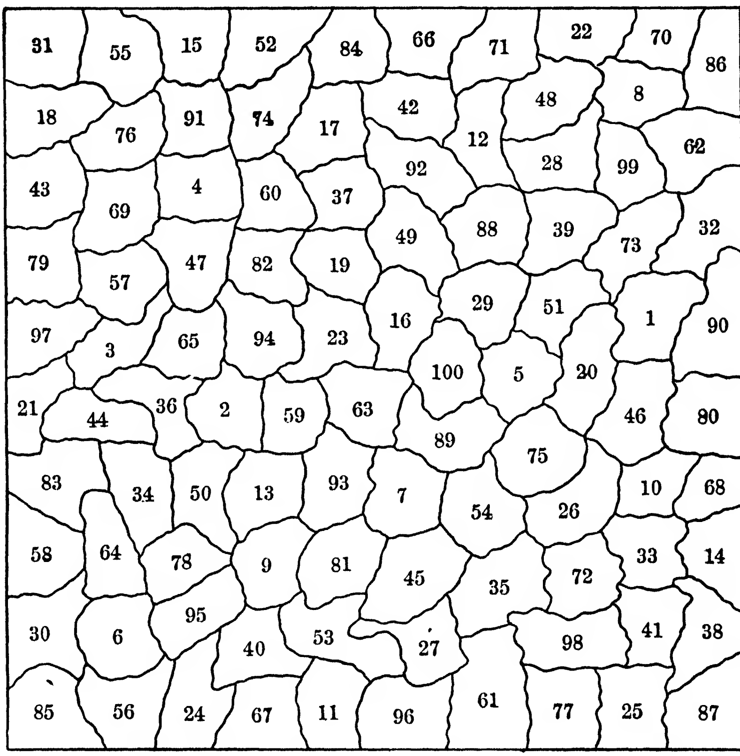

FIG. 25.

A portion (1 acre) of an ideal single-tree selection stand, managed on a rotation of 100 years, with a complete series of age classes on every acre, each occupying approximately the same area. The numbers indicate the ages of the trees occupying given portions of the acre.

will be as many ages in each stand as there are cuttings during the rotation. To secure this number divide the rotation age by the cutting cycle. (See Figs. 25, 26, and 27.)

As the interval between cuts is lengthened the amount per acre removed in a single cutting is increased in direct proportion to the increased length of the cycle. For example, if 200 board feet per acre are removed when a given stand is cut through annually, then

$10 \times 200 = 2000$ board feet per acre should be removed at each cutting if the cutting cycle is changed to 10 years. If the amount to be cut on an annual cutting cycle is known, the cut for any other cycle can be quickly secured by multiplying the length of cycle by the annual cut per acre.

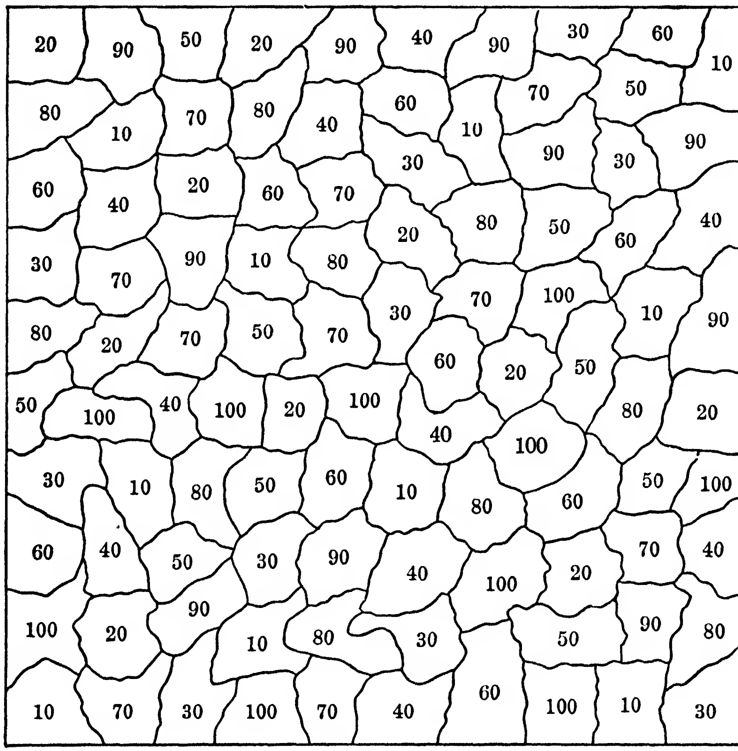

FIG. 26.

A portion (1 acre) of an ideal single-tree selection stand managed on a rotation of 100 years under a 10-year cutting cycle. Ten age classes are represented, each occupying approximately one tenth of the area. The numbers indicate the age of the individual trees. Compare with Figure 25, where a cutting cycle of 1 year is employed.

The actual percentage of the volume removed in a selection cutting is subject to great variation, depending on the length of the cutting cycle, the unit in which the volume is expressed, and the condition of the stand. When the board-feet unit is employed 100 per cent of the volume might be removed in a given cutting, provided that the old age class included all the trees of merchantable dimensions. Such a situation is not likely to occur. More commonly on a cutting cycle of 10 to 20 years from 20 to 60 per cent of the board-foot volume

would be cut. On a longer cutting cycle 75 to 85 per cent might be removed. Such a high cut is not to be recommended and can be justified only by economic conditions or by the nature of the stand, which for some reason, such as ill health or overmaturity of the timber, may require a heavy cut. In cutting so heavily, and always with a cutting cycle longer than 25 years, the unevenaged nature of

Stand 1 contains age classes: 1, 11, 21, 31, 41, 51, 61, 71, 81, and 91	*Stand 2 contains age classes:* 2, 12, 22, 32, 42, 52, 62, 72, 82, and 92	*Stand 3 contains age classes:* 3, 13, 23, 33, 43, 53, 63, 73, 83, and 93	*Stand 4 contains age classes:* 4, 14, 24, 34, 44, 54, 64, 74, 84, and 94	*Stand 5 contains age classes:* 5, 15, 25, 35, 45, 55, 65, 75, 85, and 95
Stand 6 contains age classes: 6, 16, 26, 36, 46, 56, 66, 76, 86, and 96	*Stand 7 contains age classes:* 7, 17, 27, 37, 47, 57, 67, 77, 87, and 97	*Stand 8 contains age classes:* 8, 18, 28, 38, 48, 58, 68, 78, 88, and 98	*Stand 9 contains age classes:* 9, 19, 29, 39, 49, 59, 69, 79, 89, and 99	*Stand 10 contains age classes:* 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100

FIG. 27.

Diagram of a selection forest managed on a rotation of 100 years with a cutting cycle of 10 years. The forest contains 10 stands, one of which is cut through each year, thus giving equal annual cuts. Each stand contains 10 age classes, and together the age classes in the 10 stands form a continuous series of ages from 1 to 100 years.

the stand may be jeopardized (see page 172). An average figure of 2 to 3 per cent per year multiplied by the length of the cutting cycle is considered better practice. Expressed in terms of cubic feet the percentage would be somewhat lower than for the board-foot unit.

This leads to the question as to how to determine the amount per acre which will be cut.* If all age classes are represented, each occupying the proper proportion of the area, it is easy to fix the cut. Either the annual growth or the oldest age class could be removed

* This question of limiting the cut or controlling the yield from a given forest falls under regulation. Yet under the selection method success in maintaining its typical form of forest is associated so much more intimately with proper regulation than under methods producing evenaged stands that brief mention is warranted. In fact sustained yield, either on an annual or relatively short period basis, is essential to silvicultural success under the selection method.

each year, or the periodic growth could be removed at the end of each cutting cycle, and sustained annual yield in an unevenaged stand could be maintained indefinitely. The two (i.e., annual growth and oldest age class) are identical in volume provided that the proper proportion exists between age classes. Unfortunately this ideal stand is non-existent, which complicates the problem of determining the amount to cut.

If each year (or each cutting cycle) the cutting made in a stand uncovers the right proportion of the area the proper distribution of area between the various age classes will finally result. To regulate the cutting in this way, by means of the area uncovered, usually will involve in the average unmanaged stand the sacrifice either of holding some timber far beyond maturity or of cutting trees not yet mature, depending on whether the older or younger age classes predominate in the stand. For this reason it appears impracticable in the beginning to fix the amount to be cut by uncovering a fixed percentage of the area.

A more promising method consists in making an inventory of the volume in the stand at the beginning and end of stated short periods, as, for example, 10 years (Schlich 1925). Allowance is made for material harvested during the period. The inventory at the beginning subtracted from the inventory at the end plus the amount removed during the period gives the growth during the period. The amount to be cut may then be determined on the basis of current periodic growth. If only the growth of the preceding period is utilized, a sustained yield will be obtained. It may not be an equal annual yield unless the current periodic growth in succeeding periods is the same. In applying the method, the cut should not arbitrarily be set equal to the growth of the preceding period; the age class distribution and the consequent relation which the growth of this period is likely to bear to the growth of other periods must also be considered. After the method has been in use for a few periods, the average annual productive capacity of the stand should be apparent.

In intensive application of the selection method the principle is recognized that if the best results in growth are to be secured the right amount of growing stock per acre for a selection forest must be maintained. Biolley (Champion 1922) has stated the object to be the production of the greatest value with the lowest investment in growing stock. Just what this investment in growing stock should be and how it should be distributed among the trees of different sizes must be learned from local experience. In general, the growing

stock is inventoried at short intervals, the small, middle-sized, and big wood being kept separate, as to total volume and as to growth. Through repeated periodic comparisons the best total amount of growing stock and the proper balance between different size classes can be established. It is interesting to note that examples can be obtained of increase in growth on one area from the reduction of an excessively large growing stock and on another from the enlargement of a scanty growing stock.

An illustration of this point can be drawn from selection cuttings in lodgepole pine stands in Colorado and Wyoming (Taylor 1939). There it has been found tentatively that the greatest yields can be obtained with a growing stock of about 5000 feet, board measure. In any case, on the basis of a 30-year cutting cycle, the growing stock left at the time of cutting should be not less than 3500 or much more than 5000 feet, board measure. Between 55 and 65 per cent of the volume has usually been removed in the first selection cuttings. To secure the best results in production, it is necessary that the trees reserved be of the two most vigorous classes, out of the total of four classes recognized by Taylor in his tree classification made especially for use in partial cuttings (see page 302).

No matter in what way the amount per acre to be cut has been determined, the selection of enough trees from the older age classes to give this amount should be made on the basis of the silvicultural condition of individual trees. Such points as health, rate of growth, and seed-bearing value are of especial importance. On the whole the oldest trees would be removed, but opportunity is afforded for taking out poor younger individuals and for leaving certain thrifty older trees. Trees that are growing well should be left irrespective of size. Picking out the trees to be removed in a selection cutting affords the forester the opportunity for exercise of great skill.

The age of standing mature trees cannot be determined directly without cutting or boring into them. As this is impracticable on a large scale, diameter is taken as the best indication of age, and the trees are assigned to age classes on the basis of size. For this purpose, tables showing the average age of trees of different diameters can be made by analysis of the growth of felled trees. The theory that diameter indicates approximately the relative ages of trees in a given stand applies best in a managed selection stand.

A diameter limit may then be established as a crude indication of age, with the understanding that trees below this size are in general to be reserved and those above cut. This should not be made a rigid limit but should be applied discriminatingly, certain trees above the

limit being reserved and some below the limit cut. Cutting to a diameter limit, mechanically applied, leaves the forest in less productive condition than when some selected trees below the limit are cut and others above the limit are left. As previously stated the silvicultural condition of the individual tree, particularly its capacity for increase in value, rather than its size or age, should be the deciding factor in determining whether to cut or to leave the trees. In Table III the chief reasons for cutting below or leaving trees above the limit are summarized.

TABLE III

Trees may be left above the diameter limit when:	*Trees may be cut below the diameter limit when:*
1. Exceedingly thrifty and growing fast in volume and in value.	1. Unthrifty, slow growing, and likely to decay or be killed before another cutting; at present defective.
2. Standing in groups of smaller trees and liable if cut to cause windthrow or breakage among these trees (see Fig. 28).	2. So exposed that if left they will be windthrown or broken in felling neighboring trees. This is apt to occur with tall, slender individuals growing in a group of larger trees.
3. A large seed tree is needed in or on the edge of an opening (see Figs. 29 and 33).	3. By so doing the composition may be improved or the rate of growth of more promising neighbors increased (see chapters on intermediate cuttings).
4. Needed for esthetic reasons.	
5. Required to protect soil conditions or seedlings.	

The necessity for cutting small trees below the diameter limit is felt especially in making a first selection cutting in previously unmanaged stands of evenaged or fairly regular form. In such stands many of the smaller trees have no potential value for the future because of the crowding to which they have been subjected. When released they suffer a heavy mortality (Hall 1933). Where markets can be found for small and poor material these trees should be harvested along with the larger timber. Although this practice may result in a clearcutting, sometimes enough well-formed, deep-crowned small trees can be retained to preserve the unevenaged form.

The great temptation in cutting timber under the selection method is to take too much, in other words to cut trees too young or too small and thus deplete the younger and middle age classes. This temptation exists because the young trees are intermingled with the old age classes, instead of being segregated on separate areas as in the other high-forest methods.

Even though the merchantable trees below the diameter limit are not cut, many of the smaller trees may be used in the logging opera-

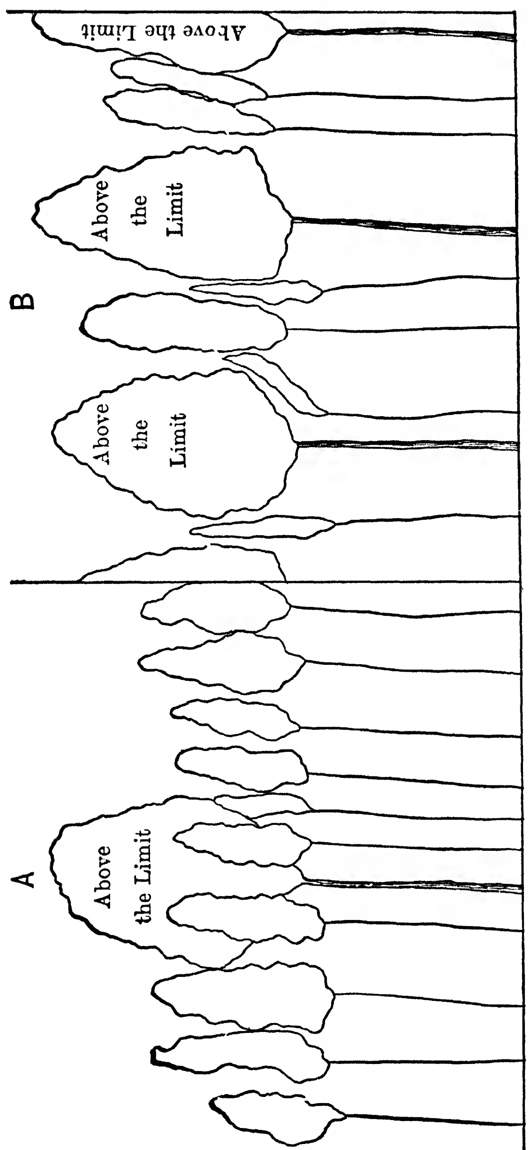

FIG. 28.

A, trees above the diameter limit for cutting should be left; *B*, trees below the limit should be cut. In *A* cut nothing; in *B* cut all trees, large and small.

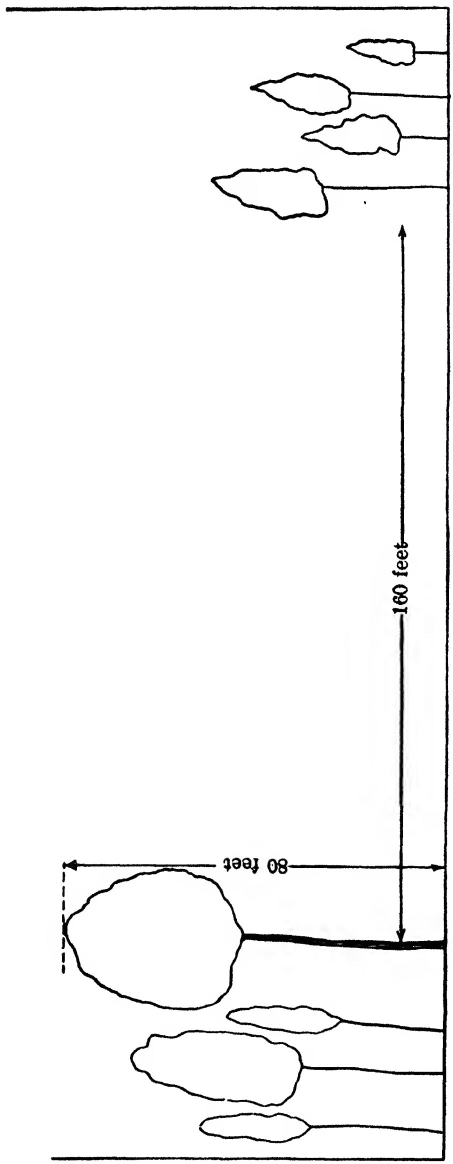

Fig. 29.

A tree larger than the diameter limit for cutting left on the edge of an opening as a seed tree.

tions, for skids, and for corduroying roads, or they may simply be destroyed in felling and getting out the timber. A certain amount of destruction is a necessary accompaniment to logging, but such wasteful use and destruction may be so extreme as to threaten the continued existence of the selection forest. In order to provide for enough old trees per acre it is necessary that numerous seedlings start every few years. These seedlings undergo a rapid decrease in numbers, because of competition and other natural causes, as they increase in size and advance toward maturity. Definite information as to the number of trees per acre of different sizes needed to secure steady production under the selection method is not available for most of our species. However, the number of trees of different sizes in the unevenaged, hemlock-hardwood forest of northern Wisconsin was computed by Goodman (1930) from extensive surveys as shown in Table IV. These figures represent conditions in the virgin forest and may not indicate the best arrangement under management.

TABLE IV

AVERAGE NUMBER OF TREES PER HUNDRED ACRES

Diameter breast high, in.	*Number*	*Diameter breast high, in.*	*Number*
2	5237	20	439
4	3023	22	357
6	2530	24	245
8	2199	26	167
10	1789	28	93
12	1401	30	39
14	1065	32	20
16	832	34	8
18	634		

As a general principle the number of trees of different sizes in the selection forest are comparable to those in the various age classes which combine to make up the evenaged forest. It is simply a question of a different arrangement in the two forms of forest. Actually the numbers are likely to be somewhat less in the unevenaged stand both because of the type of competition there, which often subjects small trees to long-continued suppression and encourages relatively wide crown development in the older trees, and because some small trees are inevitably destroyed in logging during each periodic cutting operation. The number in the older age classes of the unevenaged stand may be expected to form a bigger proportion of the total number than in evenaged forest. Nevertheless, the normal number

of trees in the selection forest might be deduced from yield tables for evenaged stands of the same species with approximate accuracy.

If to the reduction in numbers resulting from death due to natural causes is added that due to heavy cutting of medium-sized trees and destruction in logging of small trees, there may be no representatives left of certain ages to come to maturity. It is essential for successful continuous application of the selection method that waste of small trees be kept at the minimum. Fortunately there is a growing appreciation of the fact that small merchantable trees frequently cost more to log than they are worth. This is because the small logs furnish a smaller output in lumber per cubic foot of their volume than larger logs, and hence are more expensive to handle. The grade of lumber produced by such logs is less valuable than that from larger logs.

In addition the fact must be brought home to landowners and operators that young trees now under merchantable size are too valuable because of their growth possibilities to be destroyed in the logging.

The smallest tree on which a profit can be made should be determined for each forest (Ashe 1926). When this is known the incentive for utilizing trees below this size is reduced. Less encroachment upon the young growing stock of merchantable-sized trees in the selection forest should result. Various studies have been made showing for specific tracts and species the net value of trees of different sizes.

The actual figures are of course not correct for today's operations, since the studies were made before 1933, but the principle of the profit per thousand feet, board measure, being dependent upon the size of the tree is still valid.

Table V* gives examples of the results secured from studies of this sort. It will be seen that small trees yield an operating loss while others somewhat larger may yield a profit so small as to be almost negligible. Only as the relatively large sizes are attained do substantial profits accrue.

For example in the case of Douglas-fir, 14-inch trees show a negative stumpage value per thousand feet of —\$18.45, 26-inch trees of —\$.06, and so on with increasing values so that 80-inch trees have a positive stumpage value per thousand feet of \$9.38. The figures for sugar pine are even more striking, ranging from —\$21.15 to +\$27.44 per thousand feet.

* All the data in this table are taken from Table 4, p. 908, of "A National Plan for American Forestry," *Senate Document* 12, 73d Congress, 1st Session, which was prepared by the United States Forest Service.

TABLE V

NET STUMPAGE REALIZATION VALUES PER THOUSAND FEET BOARD MEASURE AND PER TREE BY DIAMETER CLASS, VARIOUS SPECIES AND REGIONS, AS DETERMINED BY LOGGING AND MILLING STUDIES[1]

	Douglas-fir Washington		*Sugar pine California*		*Ponderosa pine Montana*		*Lobolly pine Virginia*		*Red oak N. Carolina*		*Northern hardwoods Lake States*	
Diameter classes, in.	Per M ft. bd. measure	Per tree	Per M ft. bd measure	Per tree	Per M ft. bd. measure	Per tree	Per M ft. bd. measure	Per tree	Per M ft. bd. measure	Per tree	Per M ft. bd. measure	Per tree
8	.....			...	.	.	−$12 35	−$0 41	.	......	. .	... ...
10	. ..		.	..			−5 60	− 33		. .	−$2 93	−$0 18
12	.			.	$4 28	−$0 38	49	05	...	.	1 00	.09
14	−$18 45	−$1 84	−$21 15	−$2 12	− 46	− 06	5 23	85	$4 75	$0 33	5 22	68
16	−13 94	−2 23	−13 51	−2 30	3 44	65	8 31	1 99	7 60	87	9 21	1 93
18	−9 62	−2 31	−9 36	−2 15	6 19	1 55	10 80	3.42	10 10	1 72	12 87	3 47
20	−5 48	−1 92	−6 52	−2 28	9 29	3 48	13 07	5 29	12 25	2 82	16 03	5 45
22	−3 26	−1 66			12 19	6 03	15 19	8 05	14 24	4 27	18 95	7 96
24	−1 17	− 76			14 08	9 22	16 83	11 51	16 04	6 10	21 59	11 23
26	− 06	− 05			14 65	12 31	18 19	13 95	17 47	8 21	..	
28	1 00	93			14 55	15 28	19 05	16 25	19 01	10 84	..	.
30	2 19	2 36	3 33	4 66	14 38	19 12			20 55	14 28		.. ...
32	5 06	6 48			14 37	24 43	. .		21 92	18 52	. .	.
34	5 55	8 16	.		14 55	29 83			23 20	23 66		.
36	5 67	11 06			15 56	36 88			24 33	29 44		.
38	6 09	14 25			18 31	48 16		.	25 27	36 05	....	....
40	6 10	17 45	10 84	33 60						.	. .	..
50	7 15	31 89	17 87	99 89							.	.
60	8 85	60 18	24 57	226 04							....	.....
70	8 84	83 18	27 44	335 86								...
80	9 38	113 97	...	..							. .	.. ...

[1] By net realization value as shown in this table is meant the sum accruing to the timber operator, as stumpage, after deducting all operating costs from the market prices actually obtained for the product when sold. The percentages of each lumber grade produced from trees of each diameter class were determined in all studies. The current prices of each grade were applied to these percentages to determine the average price per thousand feet board measure by diameter classes. Logging and milling operating costs per thousand feet board measure for each diameter class were deducted from the lumber value to determine the net remaining. This is the realization value per thousand feet board measure. Realization value, per tree, for each diameter class is obtained by multiplying the value per thousand feet board measure by the number of thousand feet board measure per tree in each diameter class.

In some regions it is already true that prices for material contained in small logs are such as to make all trees of merchantable size well worth cutting. As market conditions improve, this situation tends to become general.

Modifications of the Selection Method. *Group Selection.* In defining the selection method it was stated that the trees cut at any one time might be standing singly or in small groups (see Fig. 30). There are certain advantages in maintaining a groupwise arrangement of trees of the same age. Less breakage among younger trees

is caused in felling and removing the oldest age class. The cost of logging may be slightly reduced. More light is provided for the development of seedlings and young trees. This is of especial importance for the so-called light-demanding species. Such species should not be managed under a method of single-tree selection. An

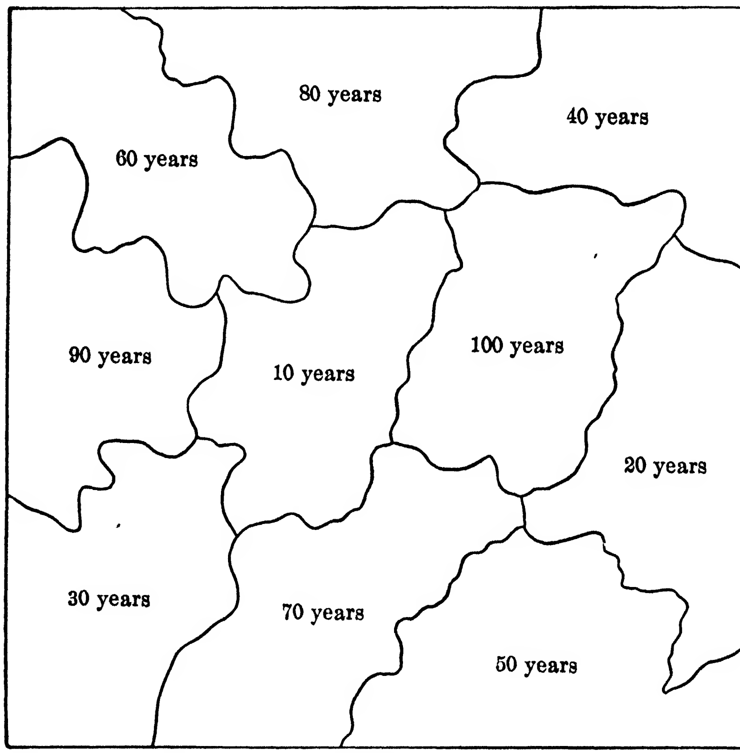

Fig. 30.

A portion (1 acre) of a stand reproduced by the group-selection method. Small groups are shown in the illustration averaging one tenth of an acre in size. Length of rotation is 100 years; length of cutting cycle 10 years. Compare with Figures 25 and 26. Ten age classes are represented in this stand, each group containing a different number of trees depending upon its age. The numbers indicate the age of the trees in each group.

advantage is that the grouping enables the individual trees within each group to grow under conditions prevailing in evenaged stands, thus obtaining greater freedom from branches and more cylindrical stems than can be secured in single-tree selection stands.

By varying the size of the group great flexibility in application is possible. The oldest groups may contain only 2 to 5 trees and from this range up to more than 100, occupying ordinarily from less than

1 to 4 acres. It is possible that even larger groups can be employed. Where the groups occupy more than a quarter of an acre the stand tends to lose its unevenaged form. With larger groups one of the distinctive characteristics of the selection method is minimized, namely, the protection afforded the soil and reproduction. The groups should be small enough so that seed can be distributed in abundance over the cleared area and so that surrounding trees may conserve soil moisture and shelter reproduction. (See Figs. 31, 32, and 33.)

Where groups too large for adequate distribution of seed from the side are cut, it becomes necessary either to reproduce the center of the cleared patch artificially or, as is more customary, to leave a few seed trees scattered over the area (see Fig. 33).

Unless an area basis is used to control the extent of the territory cut over at one time, it becomes very easy to overcut in applying the group selection method.

Strip Selection. It is evident that in single-tree selection the trees of the same age are scattered all through the stand, making the task of extracting the oldest age class a difficult one. In group selection this situation is remedied to a certain extent, but there are several groups of each age class in the stand. A further improvement may be attempted by bringing together all the trees in the entire stand of each age class. This is best done in the form of a long, very narrow strip and is known as strip selection. The adjoining age classes on the two sides are respectively younger and older than the strip between. A complete series of age classes from reproduction to mature timber is thus formed in consecutive order. This arrangement has the advantage of concentrating the logging, so that the removal of the oldest age class takes the form of a long strip cutting and results in only slight injury to younger trees. Furthermore, the trees of the same age being brought together develop among themselves as an evenaged unit. Thus the complete side closure and protection of the unevenaged stand can be secured in combination with the advantages for each age class of development in evenaged form. This is in reality the ultimate goal toward which Wagner's method (described under strip shelterwood, page 125) progresses.

The strip-selection method is theoretical in the extreme and has never been fully developed in practice. It is interesting primarily as a concept.

The Continuous Forest or "Dauerwaldwirtschaft." Since 1920 the idea of the so-called "continuous forest" has received considerable attention (Hawley 1922, Troup 1928). By a continuous forest is

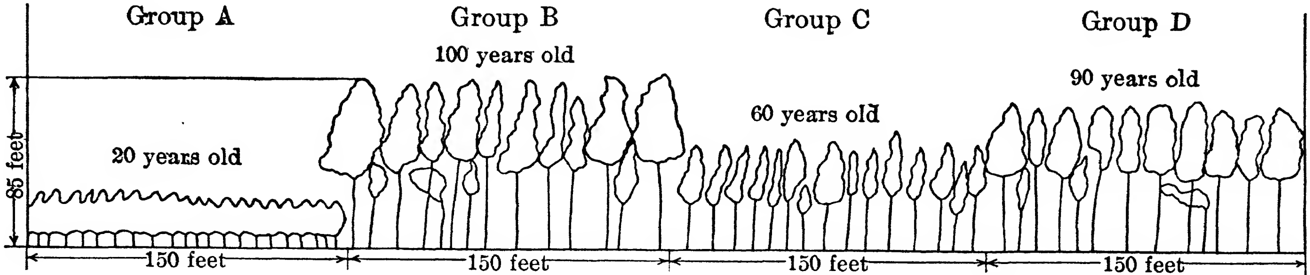

FIG. 31.

Portion of a stand managed under the group-selection method. Length of rotation is 100 years; length of cutting cycle 10 years. Four groups are shown. Group *B* is now ready to cut. Note the evenaged form of the groups. This illustrates the possibility of securing, under the group-selection system, production of timber under conditions similar to those prevailing in evenaged stands.

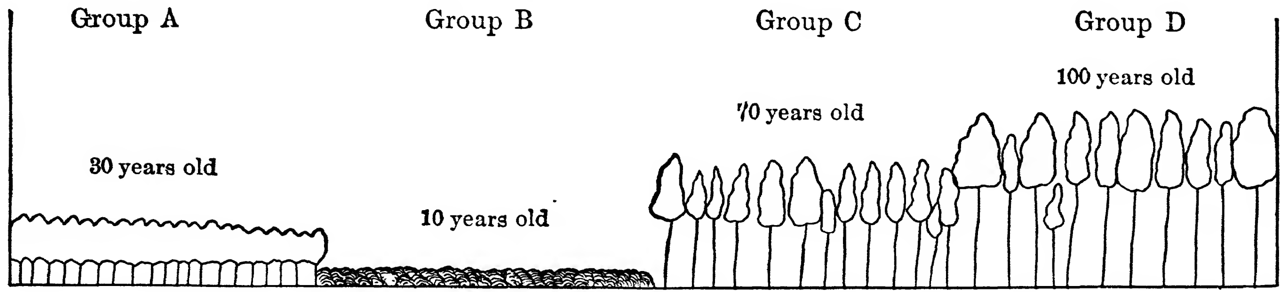

FIG. 32.

The same stand as in Figure 31, but 10 years after the cutting of Group *B*. Reproduction has started on the cleared area and is now 10 years of age. Group *D* is ready for cutting.

meant one in which no definite rotation age is fixed and no special thought is given to securing reproduction, but in which all efforts are concentrated in tending the individual trees, in improving site conditions, and in providing a continuous cover without ever exposing the

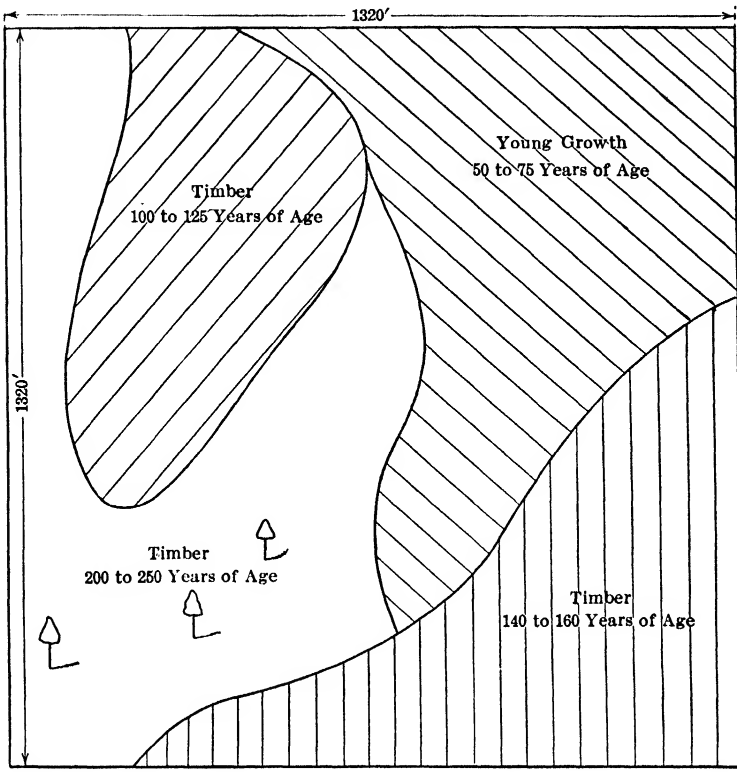

FIG. 33.

A 40-acre portion of a stand of virgin timber to be reproduced under the group-selection method. Four groups are represented in the diagram. Length of rotation is 200 years; length of cutting cycle 50 years. The oldest group is cut clear except for a few trees shown in the diagram left to furnish seed over the central part of the area. Such seed trees are needed because the group is too broad to be adequately reproduced from seed distributed from trees in adjoining groups. These groups are so large that side protection is not furnished over all the cleared area. It is a question there whether the system of reproduction should be termed clear-cutting rather than selection.

soil. The individual trees are provided ample room for fast growth and are retained just so long as their growth is satisfactory and they are not interfering with better trees. Inevitably the time comes for each individual tree when it should be harvested. The removal of

the large tree creates a gap in which reproduction has an opportunity to develop. The excellent soil conditions maintained by the method make natural regeneration easy. Indeed reproduction very probably appears under and around the larger trees many years before they are cut. Management as a continuous forest may result in maintaining an approximately evenaged stand, provided the larger trees all come to the harvest within a relatively short period of years. This is unlikely to occur. The final result will usually be the development of an unevenaged stand.

The continuous-forest idea is of greater value in emphasizing what is already known as to the importance of skillful and intensive tending of the individuals and the site than in furnishing a new method of treatment. A great deal has been written on the subject in recent years, mostly in foreign languages. Further discussion of the subject will be found on page 340.

Extensive versus Intensive Application of the Selection Method. When markets are poor and logging expensive, only the biggest and best trees are profitable to cut. Under these circumstances the selection method can be applied only in a crude way and is simple in its operation. Extensive application means long intervals between the cuts, no intermediate cuttings, growth retarded by shade, and a relatively small increment of valuable material.

In a pure stand or in a mixed stand where all the species are desirable, an extensive application of the selection method, particularly group selection, may be reasonably successful. In the ordinary mixed stands, containing one or more inferior species, bad results usually follow a crude application. The desirable trees and species are cut; the inferior are left. This type of treatment soon results in building up a growing stock of cull trees and poor species at the expense of the better ones.

If economic conditions allow the utilization of trees of all sizes and kinds, then intensive application of the selection method becomes possible. This implies short intervals between cuts, skillful tending of each tree or group, the making of intermediate cuttings, the artificial regeneration of failed places, if such exist, and a relatively high increment of valuable material.

Improvement Selection and Maturity Selection. These two modifications of the selection method are discussed on page 173.

Selective Logging or Selective Cutting. No discussion of the selection system as used in America would be complete without consideration of selective logging. This an expression, coined in relatively recent years, has been widely used by the profession because of its

popular appeal. Its usefulness is found in dealing with the general public. Technically the term has little to recommend it because too many different ideas are included. To a considerable body of landowners and lumbermen, selective logging has been the magic name which suddenly has revealed to them the usefulness and practicability of ideas which the forestry profession for several decades has been advocating. Small wonder then that the profession has accepted the term and is working under it for the widest possible application in the woods of forestry practices and principles.

Selective logging may, sometimes, but not usually, work out in application as the selection method of harvesting and reproducing a forest. A better term for the ideas involved would be "economic selection in logging," suggested by Munger (1932), but not yet used as widely as it merits. Another term "zero-margin selection," synonymous with "economic selection in logging," is used more frequently.

What are the ideas included under economic selection in logging? The primary principle is that only the timber that will pay a satisfactory profit shall be harvested. This profitable timber may occur as portions (logs) in individual trees, as entire scattered trees, as clumps of trees, or even as large areas of timber. Allocation of the areas according to time of cutting so as to get the best profit is also included. Having determined what and where the profitable timber is, selective logging harvests it and leaves the remainder — the unprofitable timbered areas, single trees, and portions of trees. This so far is only good business, and in many cases that is all selective logging may be. When, however, a business concern is sufficiently intelligent to determine by careful analysis where the line comes between profitable and unprofitable timber, it is likely to discover the potential profit in the still unprofitable growing stock, and the favorable effect on their investment of saving this young growth. In other words, careful practice of selective logging is quite likely to lead to the growing of wood crops as the next step.

Selective-logging operations may range all the way from the cutting of scattered single trees to clearcutting of areas as large as 50 to 100 acres. The operation might fall under almost any of the reproduction methods so far considered. In mixed stands there is serious danger that selective logging, unless accompanied by the added aim of growing wood crops, may result in turning the area over to the poorer species. In pure stands there is less danger of this sort. Selective logging by single trees, or groups of trees, in unevenaged stands often leaves the area in good silvicultural condition. In evenaged stands

the operation may not work so well, since the unprofitable trees that are left may be of the intermediate and overtopped-crown classes and be too slender to stand alone.

Selective logging has a wide field of usefulness. In principle it is applicable over the whole country, but by itself it is not a substitute for good silviculture.

In making full use of selective logging, for the direct benefits accruing and for its indirect value in leading owners and operators to practice silviculture, the fact should not be lost sight of that there are times when selective logging is inadvisable, as it involves the cutting only of the larger trees in the stand.

Advantages and Disadvantages of the Selection Method. The selection method with its unevenaged form of forest stands in sharp contrast to the three previously considered. For this reason it is to be expected that definite arguments in favor of and against the method can be presented.

Advantages. 1. It affords a high degree of protection to the site and to reproduction and minimizes the danger of snowslides and landslides. The crown cover is kept nearly complete, the openings made being small and scattered. No other method affords such perfect protection against erosion, injury to the physical factors of the site, or the development of a grass and weed cover. Seedlings receive shelter from sun, wind, and early and late frosts. The continuous cover of trees of all ages presents a strong mechanical barrier to the progress of land- and snowslides. Such slides rarely, if ever, start in a selection forest. The most valuable protective feature of the unevenaged form of forest, and one which is not always adequately appreciated, is the vertical closure of the stand at all times during the entire rotation. This is effective in preventing the entrance of wind. As a consequence, the interior of a selection forest has the benefit of calm, humid air and moist soil. A great fault of the evenaged stand from middle age on is that an open zone exists between the tree crowns and the lesser vegetation, if any, covering the forest floor. Only on the edge of the forest do the crowns reach to the ground. Once an opening is made the wind may sweep unchecked through the stand, often with disastrous drying effects.

2. It can be applied extensively where markets are poor and only large trees are merchantable. Poor market conditions hamper the full development of the selection idea but do not prevent the partial use of the method, for even with the poorest markets it is the largest trees that are salable. As already stated above, crude application in

mixed stands increases the percentage of the poor species and thus reduces the productive capacity of the area.

3. It satisfies the esthetic purpose best, owing to its picturesque, unevenaged form and avoidance of anything approaching clearcutting.

4. Windfall and snow breakage are eliminated or reduced to a relatively small figure. The large trees have the opportunity to develop large crowns, compared to trees in evenaged stands, and become windfirm. The small trees are well sheltered by the vertical closure of the stand.

There are two ways of protecting a stand against injury from storms. Protection may be accomplished by having a single-tree mixture of all ages, thus maintaining constantly a quiet atmosphere, or by cutting against the wind direction with uncut timber furnishing protection on the windward side of the opening. The latter plan finds its highest development in strip selection.

5. Reproduction is relatively easy to secure, owing to an abundance of seed trees and to the protection afforded the seedbed and seedlings.

6. It is the only method that maintains the unevenaged form of forest.

7. There is less danger of a disastrous fire than in forests of evenaged stands. The relatively light cuttings and the preservation of a continuous forest cover result in the maintenance of higher moisture content in the potential fuel and in a lower degree of fire danger than prevail on areas reproduced under systems producing evenaged stands. The disastrous fires which sweep through valuable timber or young growth are more likely to originate on heavily cut areas than on those treated with selection cuttings. On the other hand, sometimes an unevenaged stand may be more easily destroyed than an evenaged stand which is old enough so that the bases of the live crowns are well above the ground. Selection, with all ages on the same small area, presents a steplike arrangement of crowns which enables the fire to spread upward from the crowns of one age class to those of another, ultimately destroying the stand.

8. The unevenaged forest, with its irregularity and change within short distances, is superior to the unbroken uniformity of the evenaged form for the conservation of wildlife. A selection forest creates desirable environment for wildlife, furnishing as it does an interspersion of age classes satisfying the cruising range of many animals. This benefit would reach the optimum in group selection.

9. It is an ideal method for the small-farm forest, because it per-

mits annual or frequent harvesting of large timber. Such a forest (of 5 acres for example) is too small to be effectively organized for annual or short-period yield on a clearcutting or shelterwood method. It is desirable that the farm forest, no matter how small, should be capable of furnishing annually some of the wood and timber for use on the farm.

Disadvantages. 1. Since the mature trees are scattered throughout the whole stand and are intermixed with reproduction and small trees, logging and transportation cost more than under clearcutting methods. However, there may be offsetting credits due to taking only the large trees which are less expensive to handle and furnish material of better than average quality. This disadvantage is to considerable extent overcome when group selection in fairly large groups is employed.

2. Because of the mixture of age classes, it is difficult to prevent injury in the logging to the immature trees which form the forest capital.

3. The timber produced is of lower grade on the average, than that grown in evenaged stands. It is more likely to be knotty on account of the greater crown development of the individual tree. In evenaged stands the competition between individuals of the same age effects natural pruning to a point high up on the trunk. The crowns are restricted to a relatively small percentage of the stem, and long, clean, cylindrical stems are produced. To some extent the site on which the selection method ordinarily is employed accounts for the low grade of the timber. Selection has been applied principally on poor soils, in exposed positions, and at high elevations to provide a protection forest. On such situations the timber produced under any method is of lower quality than that produced on better sites.

4. Applied intensively it requires great skill on the part of the forester and all other members of the woods organization, owing to the complex nature of the age distribution in the stand. This requirement may be a strong argument against use of the selection method in forests where the personnel is poorly trained or inadequate in number to control the operations carefully.

The method is best suited for relatively small areas under close supervision by skilled personnel.

It is much more difficult to check results secured in the selection method than in systems maintaining evenaged stands, where reproduction is in progress on definitely demarcated areas and the results can be easily seen and measured. Furthermore the cutting in a selection forest, combining as it does in one operation the regeneration

cuttings and various intermediate cuttings such as thinnings, calls for more detailed control and higher skill than when each operation is separated and conducted on different areas, as in the management of evenaged stands.

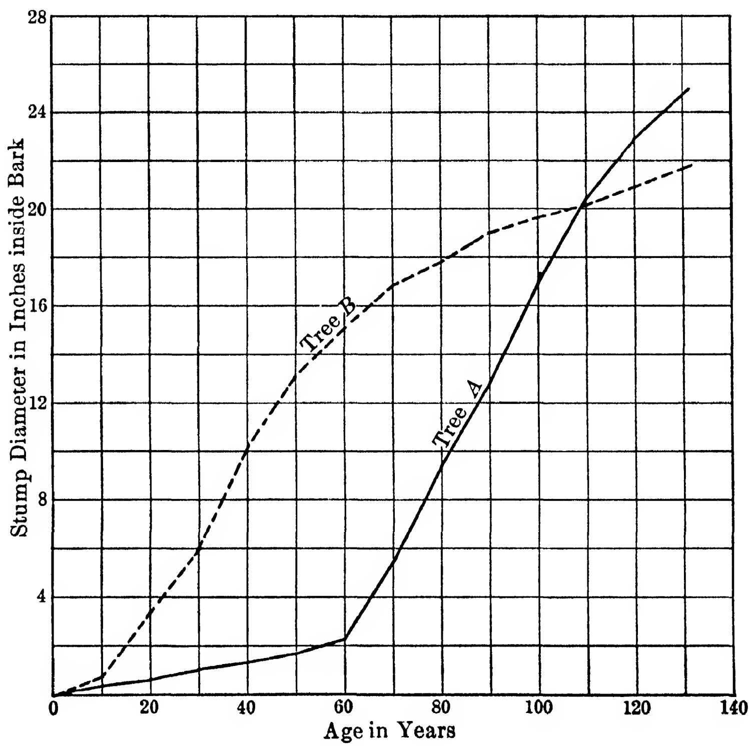

FIG. 34.

A diagram showing the diameter growth based on age of two eastern hemlock trees of approximately the same age and size growing on the same site. Tree *A* grew under conditions prevailing in an unevenaged stand. Tree *B* grew under conditions prevailing in an evenaged stand. For the first 50 to 60 years of its life tree *A* was overtopped.

Production in Unevenaged versus Evenaged Stands. Whether the method gives a higher or a lower increment than other methods of high forest has been a point of controversy abroad for many years. Some authors contend that the greater area of foliage per tree and the more complete use of available nutrients, resulting from the mixing of young and old trees with root systems penetrating to different depths, must work for greater production under the selection method. The argument against this is that the retardation of the growth of

young and middle-aged trees through shading by older ones more than offsets these items. It is not until the last half of the rotation that trees in a selection stand are completely freed from shading by taller trees. Analyses of the growth of individual trees show marked contrasts between those grown in evenaged and unevenaged stands (see Figs. 34 and 35).

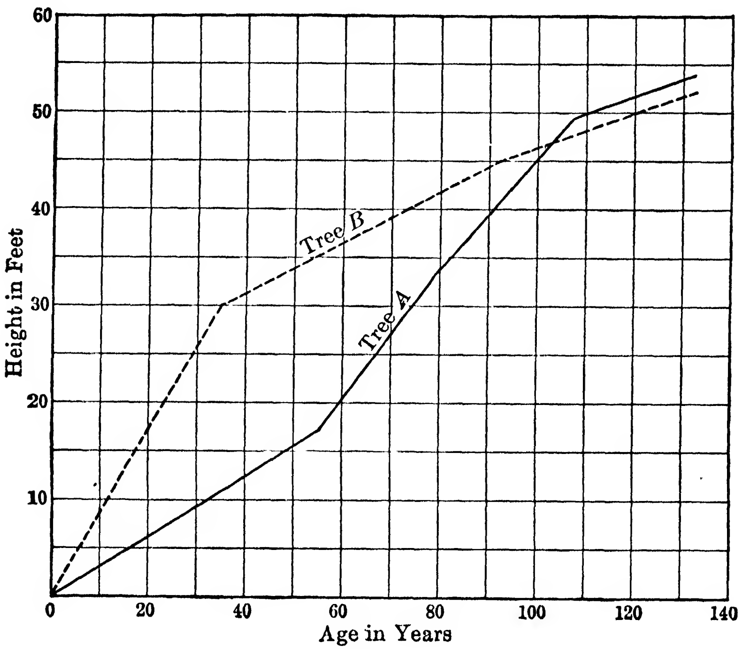

Fig. 35.

A diagram showing the height growth based on age of the two hemlock trees described in Figure 34.

The selection method maintains exceptionally fast diameter growth on the best selected stems for long periods of time. In this respect it excels the other methods. Where significant differences in unit price exist for large, as contrasted to small, diameters this may be an important advantage and result in better-quality production in selection than in evenaged stands. Under some circumstances the medium-sized stems, fairly cylindrical and free of branches, can be sold in greater volume than the higher-priced, larger-sized stems for which the demand may be small. Thus the demand for different products may determine the relative yield capacity of evenaged versus unevenaged stands.

Much of the difference in opinion as to the relative production of

evenaged and unevenaged stands arises from unfair comparisons between the two. To gauge the relative production of two methods, the same intensity of application must be employed in the management and the two stands must be on sites of the same quality. When these conditions are met the production of evenaged and unevenaged stands is likely to be equal. Carefully conducted experiments in Switzerland have yielded preliminary results which indicate, for the economic conditions prevailing in that country, a somewhat higher production in the selection forest, both in amount of material produced and in net value of the product (Balsiger 1925, Knuchel 1927). Further investigation is needed to lend greater weight to these findings. Gehrhardt (1934) does not believe that selection results in larger production than can be secured through evenaged, high-forest methods.

Application of the Selection Method. In European countries the selection method has found favor principally for sites where regeneration is slow and uncertain and where a protection forest is needed. Switzerland has a higher percentage of protection forests than other countries have. Her statistics indicate that about one third of the total forest area, and two thirds of the forest in the Alpine district, are handled under the selection method. The tendency today in Switzerland is toward further increase in the areas treated under the selection system, even on forest lands other than protection forests.

As applied today in American practice, selection cuttings have been on the whole too heavy to maintain an unevenaged form of forest and threaten to convert the forests, in which they have been made, into evenaged stands. When this happens it proves that some reproduction method other than selection was applied. Many of the cuttings made in the last decade have been misnamed " selection " when in reality examples of the clearcutting, seed-tree, shelterwood, and selection reproduction methods, together with thinnings and improvement cuttings, can be found in the various stands making up the area cut over and can be recognized on the ground for what they are.

Cuttings to be of the selection type must make use of the inherent characteristics of the unevenaged forest, namely an intimate mixture of the age classes, side protection to young seedlings, and vertical closure of the stand. When a third or less of the merchantable volume in a stand is taken these conditions should be maintained. When the cut gets up to 50 per cent of the volume it is still possible, although unlikely, that an unevenaged stand may result. But when 80 per cent of the volume is cut conversion of the forest to evenaged form is definitely under way.

Under the selection system reproduction is obtained on areas cut bare of the old trees, and under the clearcutting system the same thing is true. The distinction lies in the size of the area cleared of the old timber. In clearcutting the area cut is so large that an exposed situation for the start and development of seedlings is created. In the selection method the area exposed is so small that the surrounding forest protects the opening and provides a sheltered situation for the establishment of reproduction. Admittedly it is difficult to draw the line between a clearcut area of minimum size and a group selection cutting area of maximum size.

Excellent protection is secured where the exposed area does not exceed in width half the height of the adjacent timber. Where the opening is circular its diameter can at least equal the height of the surrounding timber. On this basis the maximum size of the groups in selection cutting would be limited to 1 to 2 acres if they were circular, while for narrow strips the area could be greater.

Another basis for distinction is whether adequate seed for stocking the cutover area could be blown in from the surrounding timber. If scattered seed trees have to be left standing on the cutover area, then the cutting is not of the selection type. However, the opposite is not true, since several of our species can seed up from the side broad, cleared areas which are unquestionably lacking in side protection.

Perhaps enough has been said to indicate that, although no arbitrary line can be drawn between clearcutting and group selection, yet many of the cuttings now classed as group selection might better be recognized as clearcuttings.

Overmaturity of timber and too great a preponderance of the older age classes present great difficulties to the immediate use of selection in forests where eventually it may be the most desirable method. The virgin forest contains an excess of the older age classes. When to this condition is added the fact that the rotation in managed forests will be much shorter than the normal life of a tree in the virgin forest, this excess of old timber becomes more pronounced.

For areas in great need of protection, selection is recognized as the proper method and is already being applied on a small scale.

Besides its general employment on areas requiring protection, which will come in time, the selection method should be favored by farmers, by others holding small areas of woodland, and by owners with whom the esthetic motive is prominent. The last group is increasing and already holds large areas in the aggregate.

Small forest owners who live on or near their forest property, particularly farmers, are in an exceptionally favorable position to apply

the selection method intensively. They furnish their own market for fuelwood and posts which are low-grade forest products, often hard to sell and yet essential to utilize, especially in hardwood forests, if intensive forestry is to be practiced. A farmer's consumption of fuelwood, fence posts, and a little lumber for building repairs and occasionally new construction will enable him to cut annually in his woodland. He requires fuelwood, at least, every year and as a practical measure can secure his annual requirements most effectively from a small piece of woodland under a selection method of management.

The Otsego Forest Owners Cooperative, an organization of small forest owners with headquarters at Cooperstown, N. Y., has encouraged the application of cuttings of this type. Forest holdings of the members are characterized mainly by northern hardwoods, hemlock, and white pine. Their members are advised to cut annually, and to return to the same section of their woodland for successive cuttings every 3 to 6 years. The best plan is for the owner to divide his forest into as many sections as there are years in his cutting cycle and to cut in one section each year. If desired, the whole forest can be cut over the same year. If this is done, the cutting cycle should not exceed 3 years as the owner can store and use up before it spoils a 3-year's supply of fuelwood but not much more. The amount removed should be about 3 per cent a year of the basal area, or 10 per cent on a 3-year cutting cycle. This is a very light selection cutting but ideal in the northern hardwood-hemlock type. The trees taken out should be those that will not lay on wood volume of desirable quality, slow-growing individuals interfering with better trees, and trees that have reached maturity. The cutting should be distributed throughout the range of diameters down to the minimum size suitable for cordwood. This cooperative operates a mill and buys logs from the members, thus providing them a market for the small quantities of logs obtained in their annual cuts. A market for logs and the ability of the farm owners to use the low-grade products themselves are essential factors in making such light cuttings practicable.

Another opportunity, for what may be only temporary application of the selection method, is found in some portions of the country where young and middle-aged stands of second growth compose the forest with very little if any mature timber. The oak and mixed hardwood forests of Connecticut furnish an example. In such forests merchantable saw timber can be secured only by picking out the relatively few bigger trees, usually in evenaged stands of the 41 to

60 age class. Selection cutting is the most practical method for saw timber in such stands. It starts the transformation of evenaged stands over to unevenaged form, but in the second cutting 15 to 20 years after the first the method may be abandoned in favor of shelterwood. Considering the silvical habits of the more important species, chiefly oak, it is likely that shelterwood will be the method to use permanently, although not until a good proportion of the stands advance in age to 70 years and the market for hardwood in cordwood sizes expands sufficiently to absorb the available supply. Meanwhile, application of selection cuttings removing about 35 per cent of the merchantable volume will enable forest owners to obtain some saw timber and should increase the current growth of the forest.

The influence of economic conditions and the silvical habits of the species may occasionally point to the adoption of the selection method for the production of timber on a large scale. An example is furnished by lodgepole pine in the Rocky Mountains.

Lodgepole grows on areas which are often spoken of as protection sites but yet are lands which from their location topographically are not the protection sites of the locality, the real protection sites being found in timbered areas located above the lodgepole type. Stated in another way, a great share of the lodgepole pine type may be used primarily to grow timber without interfering with its protective value. Theoretically this situation would permit either shelterwood or clearcutting as well as selection. The United States Forest Service, after trying various forms of clearcutting and the seed-tree methods, has swung around to selection as best meeting the market requirements of the region and fitting in with the silvical habits of lodgepole pine. Certain forms of stand demand immediate reproduction under other methods, but the indications are that for lodgepole pine selection will be on the whole the best method of reproduction and the unevenaged forest the most desirable form.

From the utilization standpoint, selection is preferable to clearcutting in lodgepole pine stands because it does not require cutting such large quantities of small material which the market cannot absorb. Furthermore, reproduction on exposed clearings is more abundant than after selection cuttings, and this is a disadvantage for clearcutting since young lodgepole usually starts too densely on clearings, cannot be thinned without expense, and reproduces in adequate amount after selection cuttings. Thompson (1929) advises removing 30 to 40 per cent of the volume in selection cuttings at intervals of 20 to 30 years, although he states that the condition of many stands requires removal of as much as 60 to 70 per cent of

the volume. Taylor (1939) more recently has emphasized the importance of leaving after selection cuttings an adequate growing stock, neither too large nor too small, made up of the most vigorous classes of trees (see page 149). Some of the silvical habits of lodgepole make the species unadaptable for permanent management under the selection method. Lodgepole pine needs abundant light to keep ahead of its associates and has a tendency to develop in evenaged stands. Ultimately cuttings of the shelterwood rather than the selection type may prove most satisfactory in managing this species.

Commercial cutting of redwood is now done to a large extent on a selective-logging basis in contrast to the former system of clearcutting. The change has been brought about by a shift from donkey engines and wire-rope systems to the use of heavy tractor units in logging on suitable ground. It is questionable whether these cuttings should be classed as of selection or shelterwood type. Person and Hallin (1942) found that seedling regeneration of redwood was satisfactory after selective cutting, and that redwood seedlings made a better showing than the associated grand fir and Douglas-fir under the same conditions.

Engelmann spruce and Douglas-fir (Rocky Mountain form) are also cut under the selection system on the National Forests in the Rocky Mountain region (Thompson 1929).

Further details for applying the selection system in stands of Engelmann spruce and alpine fir are suggested by Connaughton (1943). Loss in the reserve stand from spring winds after cutting has been a weakness of methods previously used for Engelmann spruce. To minimize losses from wind a method described as salvage group selection is proposed. A maximum cut of 50 per cent of the merchantable volume is allowed in the form of clearcut groups 66 feet in diameter and occupying about one third of the area. The timber between is left dense and untouched except for the salvage of trees with dead tops. The group arrangement of the cuttings is also designed to improve water yield (an important function of the Engelmann spruce-fir type) by decreasing interception, increasing snow storage, and prolonging snow melting.

The northern hardwoods type, of commercial importance in the Lake States and northeastern United States, is composed principally of hardwoods and hemlock. Most of the species are shade enduring and well suited in silvical habits for management under the selection system. The old-growth stands are unevenaged and contain many trees wholly or partly cull because of heart rots. If these defective trees can be marketed, excellent results follow application of selection

cuttings (Eyre 1939). On the other hand, if only the sound trees can be utilized, selection cuttings leave a stand encumbered with cull trees which prevent the development of a satisfactory new crop. A selection cutting removing 25 to 50 per cent of the volume and leaving a growing stock of sound trees represents the ideal kind of cutting where it is practicable. The Goodman Lumber Company operating in northeastern Wisconsin has been applying selection cuttings since 1927 (Carr 1939). They remove 50 to 60 per cent of the merchantable volume, taking most of the trees above flexibly applied diameter limits varying from 18 to 22 inches. Individual tree selection is also practiced to secure proper opening of crown cover for increased growth and avoid such large openings as would lead to windfall. The cutting cycle is 20 years.

Forest management in harvesting ponderosa pine has with few exceptions applied the selection system. Only a few years ago standard practice by the United States Forest Service was a form of group selection removing 75 to 80 per cent of the merchantable volume, with the intention of returning for a second cut only after 35 to 60 years. Railroad construction was usually necessary for logging the timber, and this required a heavy cut to justify the high charge per acre for transportation. The heavy cut rendered impractical as early a return for a second cut as the light-demanding habit of the tree made desirable. Removal of more than 75 per cent of the merchantable volume was far too heavy a cutting to maintain a selection type of forest. The groups cut were so large that at least four large seed trees per acre had to be reserved to ensure reproduction. Cutover areas gave the impression that seed-trees or clearcutting methods were in use more often than selection.

Modern developments in transportation which made possible the replacement of railroad logging, in whole or in part, by trucks and tractors, have so changed economic conditions in the ponderosa pine regions as to make possible a changed type of management, featured by lighter cuts, shorter intervals between successive cuttings, and consequently a closer approach to the true selection type of management.

The advantages of lighter cuttings in ponderosa pine were recognized long ago before the change from railroad to truck transportation made its application possible. One advantage is that the entire area of overmature ponderosa pine can be more quickly covered, thereby preventing the annual loss now resulting from the mortality in the virgin stands. Until such cuttings are made the virgin stands remain in unproductive condition, net growth per acre usually being a minus

quantity. Lighter cuttings leave a growing stock nearer the optimum for highest growth, in quantity and quality, and protect the site and reproduction better. Necessary expenditures for slash disposal are likely to be less after light than after heavy cuttings.

Special names, "*maturity selection*" and "*improvement selection,*" have been given to two of the modifications of the selection method as now applied in ponderosa pine. As they present a contrast it is worth while to discuss them in more detail.

Maturity selection was developed for the ponderosa pine type in eastern Oregon and Washington. It is defined by Munger (1941, p. 303) as follows:

"*Maturity selection system.* A form of tree selection which contemplates the removal of the trees which are biologically and financially most mature, as judged by a combination of the factors (1) mortality probability, (2) quantity and quality growth rate, and (3) carrying charge (or interest) based on current capital value."

The removal of 20 to 60 per cent of the volume is contemplated, the usual amount taken being near 40 per cent. Logging costs are not more than 50 cents per thousand greater in cutting only 40 per cent of the volume as contrasted to the old 80 per cent. The greater cost is more than offset by the higher average quality of the logs. A second cut is expected in not more than 30 years.

Marking for cutting under the maturity-selection system requires that each tree be rated on a biological and financial basis. The first step is to estimate the tree volume by log grades and find its conversion value. Next, from tables based on diameter and tree class, the tree's growth-rate percentage and mortality-probability percentage is obtained. With these data, and allowance for a 3 per cent interest rate on conversion value of the tree, the carrying charges for holding each tree can be computed and compared. The trees with the highest carrying charges (interest on their capital value, minus growth percentage, plus mortality percentage) are felled, up to the limit of the cut allowed, on the assumption that such trees are biologically and economically the more mature. If the method is strictly applied no trees which have minus conversion values, as for example wolf trees, are cut, no matter what their species. In practice a reasonable deviation from this rule is likely to be made. Consistent application of the formula will, however, result in retaining some large, high-value trees, which are very thrifty, while removing some low-value trees (provided they do not drop into the minus-value group), which it is desirable to get out of the stand.

Pearson (1942) terms the light type of cutting which he advises for ponderosa pine "*improvement selection*." Described in his own words: "*Improvement selection* is, as the name implies, a form of selective cutting which stresses improvement of the remaining stand. In addition to economic utilization of the crop, it strives to create a better growing stock with each successive cutting. It favors the class of trees which promises the greatest contribution in growth and value to the stand as a whole."

Improvement of the growing stock is the cardinal principle of this system. To this end minus-value trees, such as wolf trees, are felled or poisoned, provided that their destruction will release smaller trees of high potential value. Merchantable trees that have attained the peak of value increment and are now the least promising for the future are cut. Since in the ponderosa pine type such individuals are usually the largest trees and those containing the highest-quality timber, very much the same trees under this class are taken out as in maturity selection. Some low-grade trees having little future promise, as well as small trees in dense stands which need thinning, are cut in improvement selection. In an example cited by Pearson 53 per cent of the volume was removed, leaving a reserve of 8500 feet, board measure, per acre. Future cuttings planned for the area are a light cutting of about 30 per cent in 10 years, and then subsequent cuttings removing 35 to 40 per cent of the volume at 20-year intervals.

These two modifications of the selection system, for use in the same forest type, illustrate the importance of local conditions such as climate, soil, nearness to markets, salability of products, ownership, labor situation, and protection problems in the application of silviculture. As a matter of fact, maturity- and improvement-selection methods are both classified under selection, and the words "maturity" and "improvement" are each redundant. As concerns "maturity" the principle of the selection system is the removal of trees as they mature, and the practical question is simply what criterion to apply in judging maturity. As concerns "improvement" all practice of forestry has as an underlying purpose, whether specifically stated or not, the improvement of the stands managed. For identification tags, to keep separate these two modifications of selection in ponderosa pine, the names may be useful.

It should be borne in mind that neither one has any monopoly, as against the other or as against other methods, of the ideas involved in "maturity" or in "improvement." Schenck, one of the earliest forest practitioners in America, in managing yellowpoplar approxi-

mately half a century ago, made use of interest rates in determining maturity. He also strove to improve the growing stock in the forests under his charge.

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CHAPTER VIII

THE COPPICE METHOD

Definition. A coppice forest is one composed wholly or mainly of sprouts, and the coppice method of reproduction accomplishes the renewal of the forest principally by sprouts, although usually with a mixture of seedlings. The stand is cut clear, and reproduction starts immediately from sprouts from the stumps or roots of trees which formed the old stand, often supplemented by scattered seedlings and seedling sprouts on the ground at the time of cutting. The rotation is always short as compared with rotations in the high-forest methods. The coppice method is sometimes spoken of as simple coppice or the sprout method.

Form of Forest Produced. The coppice method produces an even-aged stand, more regular in form than the majority of those established under other reproduction methods. Sprout reproduction originating all in one year explains this regularity.

Details of the Method. The coppice method requires only one cutting which takes the entire stand, leaving a bare area. Within less than a year the sprouts start and the new stand has replaced the old (see Fig. 36). It is evident that ability to sprout is an essential requisite for any species, if it is to be reproduced under the coppice method. Therefore the method is more common for hardwoods than for conifers.

Sprouts originate from dormant or adventitious buds, principally the former, and with most species start from the root collar, side, or top of the stump. Those from the root collar are the most abundant and develop into the best trees. A few species sprout mainly from the roots. Not all suckers can be depended upon to reach maturity as they are likely to be affected with decay from the mother root.

It is important to know, not only whether a species sprouts, but also where the sprouts originate—in the stump or in the roots—and if in the roots whether the root suckers will grow to merchantable size.

A species capable of reproducing by sprouts does not always produce a satisfactory crop of sprouts. This variability in sprout

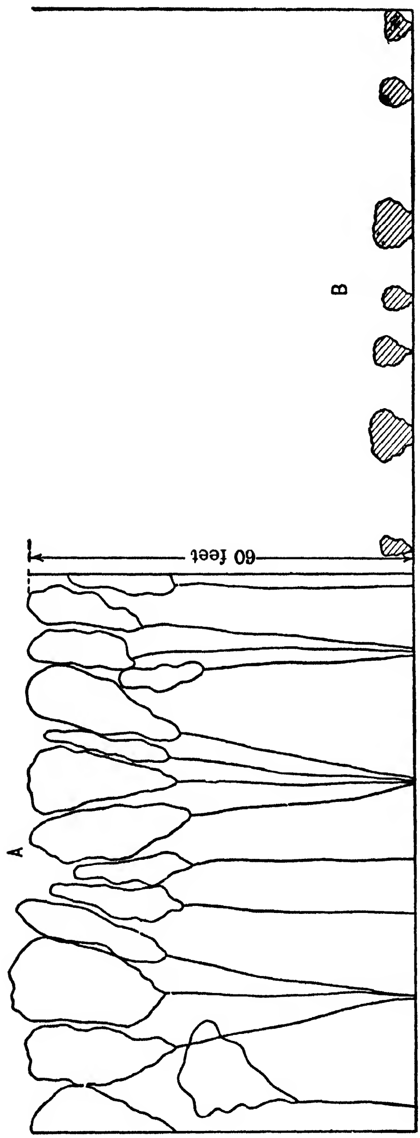

Fig. 36.

A stand reproduced by the simple coppice method, before and after the reproduction cutting. *A*. Stand ready to cut clear. *B*. Same area one year later with clumps of sprouts growing from the stumps of the felled trees.

reproduction may be attributed to several factors of which the three following are the most important:

1. Age or size of the stump at time of cutting.
2. Season of the year at which the cutting is performed.
3. Height and characteristics of the stumps left by the choppers.

Age or size of the stump at the time of cutting. As trees grow older and larger their sprouting ability gradually decreases. The reasons for this have not been accurately determined. Possibly, as the period of seed production is reached, the tree loses its ability either to develop dormant buds into living shoots or to form adventitious buds. Beyond a certain age only a few trees of a given species can be counted on to sprout after cutting. The age varies considerably between species. White oak in Connecticut sprouts feebly from stumps over 60 years of age. The thriftier the tree and the nearer it is to its maximum rate of growth when cut, the better the stump sprouts. This period of greatest thrift and highest growth rate comes during the first part of the tree's life and may be considered as passed by the thirtieth year.

Season of the year at which the cutting is performed. The best time to do the cutting is in the period when the trees are in the dormant condition. The presence of sap in the wood at the time of cutting increases the liability of the stumps and sprouts to suffer injuries, such as tearing of bark, breaking off of sprouts, and damage by frost.

Stumps of trees cut in the late fall and winter sprout more vigorously than those cut at any other time of year. At the end of the first year, the height of sprouts from winter-cut stumps frequently is twice that of sprouts from stumps cut during the growing season.

Stumps cut in early summer may sprout the same season, but sprouts starting so late make feeble growth and often are killed by frost. Stumps cut after midsummer are likely to remain unproductive or furnish sprouts only in the following year.

Height and characteristics of the stumps left by choppers. For the most vigorous sprout reproduction stumps should be cut low, smooth, and slanting (see Fig. 37). A low stump keeps the sprouts right at or close to the root collar as their place of origin. This in turn enables the sprouts to form independent root systems quickly. The stump itself if cut low is more completely covered by dirt, litter, or snow, and thus is better protected against extremes of cold and heat. If very low sprouting is desired the stumps may be cut level with the ground.

The axe should be used in preference to the saw for felling where sprout reproduction is desired. A smooth cut, particularly one made on a slant so that water sheds off the stump, increases the time during which the stump will remain sound. It is easy to prepare such a stump with an axe. Felling with the saw leaves stumps

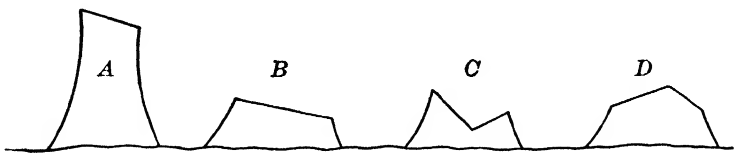

FIG. 37.

Good and bad stumps from the standpoint of sprout reproduction. Stump *A* is too high and is likely to produce sprouts from the top or side. Stump *B* is the best of the four, being low and cut smooth and slanting so as to shed water. Stump *C* is very bad as the notch will collect water. Stump *D*, though better than *A* and *C*, is not so good as *B*.

with relatively rough surfaces, the fibers being torn instead of smoothly cut as with an axe. This, however, is of little practical importance as regards rate of callusing. When a stump is small, as it is under a low rotation, it may become entirely callused over. On the rotations common in this country stumps ordinarily remain uncovered.

Decay from the old stumps may in the course of time infect the butts of the new sprouts. The progress of such decay varies greatly with the species of tree. Some species are affected very slowly and to a small extent; in others, decay spreads quickly and is exceedingly injurious.

Roth and Sleeth (1939) in studying 7 species of oak found that considerable butt rot occurred in sprout oak stands. Decay in the sprouts came from the old stumps and entered the sprouts only after heartwood had begun to form, making a connecting union with the heart of the stump. Height above ground at which sprouts originate on the stump was an important factor in determining the presence of decay. Only 10 per cent of the sprouts originating below ground level showed decay, at ground level only 20 per cent, but at 4 inches and more above the ground more than 40 per cent of the sprouts contained decay.

Evidently cutting the stumps down close to the ground thereby forcing the sprouts to originate closer to the ground than 4 inches is an important point in coppice management of oak.

The longer the rotation the more likely it is that decay may

seriously infect the sprouts, because of the increased time available for the action of the injurious agency and because the sprouts on large stumps are more quickly infected than those on small stumps. The ideal condition, from the standpoint of resisting decay, would be to have the new sprout take over completely the root system of the old stump. Then the entire root system remains alive, the top of the old stump may become completely callused over, and less opportunity is afforded for decay to attack the sprout. Leffelman and Hawley (1925) have shown that for the oaks in southern New England this ideal condition is attained only for stumps of an average size of 2 inches and under.

Except for the greater liability to butt rot, the tree of sprout origin should produce material as good in quality as that grown in seedling trees.

The question is sometimes raised as to the ability of sprouting species to reproduce vigorously after repeated generations of sprouting. Two important points appear to be involved here, first, the effect of decay in spreading from old stumps and so attacking the new generation of sprouts, and second, the gradual deterioration of the site and lowering of production, because of frequent exposure and large use of mineral substances by the sprout crops (see Disadvantage 3). The first point has just been discussed. It is believed that little loss in vigor of sprouting occurs as a result of the entrance of decay. What does happen is that with susceptible species decay may advance so rapidly, from old stump to new sprout, as to prevent (except on very short rotations) the production of crops free from early and serious infection.

The practice of silviculture in this country has not been pursued long enough to furnish first-hand knowledge as to the second point. European opinion inclines toward the belief that continued cropping on coppice rotations reduces production. Reduced production may not be experienced on the moister soils, to which the coppice method is best adapted, and which afford a larger supply of available nutrients than poor dry sites. One example (Bourne 1924) may be cited where oak coppice worked for 200 years, on a rotation of 18 to 20 years on a relatively poor site, has maintained its vigor, and deterioration of the site has not resulted. The good results are explained by special measures taken at the end of the rotation to preserve the physical properties of the soil and to force low sprouting on the old stumps.

Since sprouting ability decreases with age and is at its best during the first few decades of a stand's life, it follows that rotations for

the coppice method of reproduction should be short. How short will depend principally upon the inherent sprouting ability of the species, together with its rate of growth and the age at which salable products can be obtained.

If vigorous sprouting alone were to be considered, rotations of less than 10 years would be desirable. This period is much too short to be generally practicable, because the products grown would be small and salable only under the most intensive market conditions. By extending the rotation to 40 years a good yield of cordwood can be secured. Although the cordwood is more profitable than the brushwood produced on a rotation of less than 10 years, it is still an inferior product and often unprofitable. In order to secure lumber a rotation of 60 to 100 years will be found necessary with most of the species that can be reproduced by sprouts.

When a very short rotation (less than 10 years) is used, fully stocked and vigorous sprout reproduction may be expected. With a 40-year rotation there may still be satisfactory sprout reproduction, but with a 60- to 100-year rotation sprouts cannot be counted on to establish a fully stocked stand. Even though all the stumps of the trees in the old stand should sprout, which is unlikely, the stocking would be incomplete because these old trees are too few and stand too far apart to reproduce the area completely by sprouts.

When the rotation is lengthened to 40 or more years, provision for a mixture of seedling reproduction to supplement the crop of sprouts is essential. A certain amount of seedling reproduction is advisable from time to time, even in a stand fully stocked with sprouts. It is particularly important with species in which the trees of sprout origin are susceptible to rapid butt rot, or are otherwise undesirable, as contrasted with seedlings.

Seedling reproduction can be secured artificially by setting out plants in the spots which the sprouts have failed to stock. Strong transplants should be used for this purpose and after planting they should be cut back to the ground. They send up vigorous sprouts which compete more successfully with the coppice than could the original transplants. Fortunately, when the rotation is lengthened to 40 years or more, the parent stand usually is old enough to produce abundant seed and natural reproduction can be relied upon to furnish a mixture of seedlings with the sprouts, especially if the stand is thinned.

As the amount of seedling reproduction increases, the method resembles shelterwood or clearcutting rather than simple coppice. In the new stand there may still be found an appreciable percentage

of trees of sprout origin. This condition does not necessarily brand the method as simple coppice, unless sprouting is the predominating origin of the regeneration. With species which occasionally sprout at ages beyond 60 years, it is to be expected that scattered trees of sprout origin will appear in many stands managed under other reproduction methods.

It may be necessary to assist the seedling reproduction (either natural or artificial) for a few years in overcoming competition with sprouts, which grow faster in early life and may overtop and suppress the seedling reproduction that it is desired to establish.

In the coppice method preparation of the ground to secure favorable conditions for germination and for the development of young reproduction is unnecessary. The sprouts are able to compete successfully with underbrush, and they are independent of litter conditions and ground cover.

Disposal of the tops left after the clearcutting of the area is not essential from the standpoint of satisfactory reproduction. Considerable accumulations of hardwood brush do not prevent the sprouting of stumps located under the brush, although occasional stumps may be so deeply covered as to smother the sprouts. Usually where the coppice method is employed a close utilization is possible and the tops that remain are relatively small. Joranson and Kuenzel (1940) found that covering white oak stumps with slash to a depth of 1 to 2 feet decreased the number of sprouts originating per stump. This was considered a favorable result as it concentrated growth on a smaller number of stems.

Since the coppice method is a clearcutting operation, it is advisable that large cutting areas be avoided, to prevent exposure of the site. Where danger of exposure makes such procedure advisable, cutting can be done in narrow strips alternately or progressively arranged.

Pollarding. Sometimes trees are severely trimmed or lopped back with the intention of reproducing a growth of sprouts from the portion of the tree remaining. The sprouts are harvested when relatively small, and another crop is started. This is known as pollarding. The point of pollarding is usually between 4 and 12 feet above the ground.

Pollarding may be described as the coppice method operated on a short rotation and with abnormally high stumps. The method is first started when the original trees are 10 to 20 years old. A pollard head should remain productive for 60 to 100 years, but it finally becomes useless or unproductive through decay. The method is particularly suited to lands frequently or deeply flooded, as the

pollard head keeps the tender sprouts out of the way of injury by water or floating debris and prevents their being submerged. Pollarding can be, and usually is, combined to advantage with partial use of the land for grazing or agricultural crops. The pollard heads are arranged far enough apart so that good grass for grazing can develop between them, while the sprouts are above the reach of the animals. The pollard heads may be placed still farther apart in rows where they serve as fence or vineyard posts. Agricultural crops are then grown between the rows of pollard heads. (See Fig. 38.)

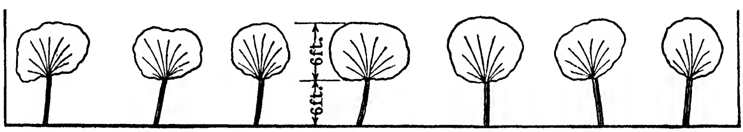

FIG. 38.

A row of trees managed under the method of pollarding. The young shoots above the pollard heads are 1 year old and ready to be cut.

Pollarding is not always restricted to low-lying streamways. In the Basque country of southwestern France and adjoining portions of Spain the growing of pollarded oak forests (principally *Quercus pedunculata*) is carried on upon the hilly uplands and slopes of the region (Balie 1933).

The trees stand about 20 to 25 feet apart and have been pollarded at heights of 8 or more feet above the ground on a rotation of around 15 years. Originally the trees were established in this way in order that underneath them could be grown crops of various plants such as ferns and heather which were used by the farmers in their agricultural and stock-raising operations. Large numbers of domestic animals range through the region, but they cannot reach and injure the pollarded portions of the tree. The old method of completely cutting off the entire top of each tree is now varied by several types of partial pollarding on a 10-year rotation. This may be done by what is known as the bipartite method, whereby half the branches are removed at one time and 3 years later the other half are cut. In other cases the selection method of pollarding may be employed, whereby the larger branches are cut every 10 years to about an 8-inch limit.

It is believed that stands of pollarded oak may be as productive as oak coppice.

Rotations in pollarding must be short, as the individual sprouts cannot develop independent root systems and, if allowed to reach large size, might break off from the pollard head and injure it.

From 1 to 15 years covers the range in rotation, ages less than 5 being most common.

Advantages and Disadvantages of the Method. The coppice method with its comparatively short rotation and reproduction from sprouts stands in strong contrast to the four high-forest methods which depend on reproduction from the seed.

Advantages. 1. It requires only a small growing stock and hence a low financial investment. This is a consequence of the short rotation and holds true particularly for the very low rotations.

2. Although the wood produced is comparatively small and poor, the net return on the investment is relatively high, owing primarily to the short rotation and the small amount of capital invested.

3. The period of most rapid growth(i.e., early youth) is taken advantage of by cutting the stand when this period is past and starting a new crop. Hence the amount of wood produced per year should be greater than under high-forest methods. The fact that sprouts grow faster in early life than trees originating from seed supports this theory.

Short coppice rotations, though including the period of most rapid growth so far as low-grade products like cordwood are concerned, are not long enough to grow large amounts of better-grade products like lumber. Therefore the advantage of faster growth under the coppice method is true only for small products.

4. It is subject to comparatively few injuries; because the trees are still young and vigorous at the end of the rotation. Those that do occur can be made good with less sacrifice than under methods which require longer rotations.

5. The securing of reproduction by sprouts is simple and certain as compared with reproduction from the seed.

Disadvantages. 1. Requires that small products such as cordwood or pulpwood be salable. For intensive application on rotations of less than 15 years it is necessary that a market exist for very small material. Lumber forms only a small percentage of the volume, even on the longer coppice rotations.

2. It is unsatisfactory from the standpoint of the public welfare because:

(*a*) It fails to provide the lumber needed in the industries. This disadvantage has particular weight in the management of publicly owned lands.

(*b*) Because of its low growing stock, it does not provide a reserve supply of forest products for the future or to meet extraordinary demands.

3. It tends to exhaust the available mineral substances in the soil, because the product consists so largely of small branches and young wood which contain a greater proportion of minerals than larger and older wood.

4. The sprouts are frequently damaged by frost. Young sprouts are apt to continue rapid growth until late in the season and fail to lignify before the fall frosts. The injury results in the killing back of all or parts of the last year's growth of the sprouts, which, if not entirely killed, may continue growth the following season. Frost injury may be so serious as to make the method inapplicable on sites subject to frost, such as the higher altitudes.

5. Esthetically it is not a desirable method, since it produces a relatively low forest and one too monotonous in its regularity to be attractive.

6. It is considered the poorest method from the protection standpoint. The frequent clearcuttings and the relatively low total height attained by the stand result in exposure of the soil. The tendency of coppice to exhaust the mineral contents of the soil is likely to be important on protection sites which are usually shallow-soiled and of poor quality. The prompt start after clearcutting and the rapid growth of reproduction have the effect of preventing the complete exposure of the soil which may follow clearcutting with reproduction from the seed.

Application of the Method. Coppice with its small growing stock, low investment, and quick returns appeals to private land owners, but it is not a satisfactory method for the publicly owned forest because of its failure to produce the lumber required as an economic necessity by the community.

Before a private owner can avail himself of the coppice method and its attendant advantages, there must exist both excellent markets for small-sized forest products and valuable species suited to the area and capable of reproducing by sprouts. The lack of one or both of these essentials prohibits the adoption of the coppice method.

In Europe the coppice method has been applied principally in the low lands adjacent to rivers, where the soils are comparatively rich and moist. Mountainous regions and other places where the fall frosts come so early that the sprouts do not have time during the short growing season to lignify thoroughly are unsuited to coppice production. In Germany coppice is considered applicable at elevations below 2500 feet.

The rotations abroad are very low, ranging from 1 year for willow rods for baskets up to 5 to 15 years for brushwood, hoop poles, vine

props, and oak tanbark, and from 20 to over 30 years for cordwood. In Europe the tendency has been toward a decreasing use of the coppice method. For the smaller private owners the method is more attractive than for other classes of forest owners.

In North America the principal field for the coppice method lies within the central forest region. There the requirements for a climate with only moderate frost danger and for species of good sprouting ability can be met. The coppice method is being applied throughout this general district.

Usually certain special market requirements for one or more forest products have led to the development of coppice stands. The culture of the basket willow, grown on a limited scale in this country, is an example of coppice production on the shortest possible rotation — 1 year (Hubbard 1904).

Clearcutting of hardwood stands with sprout reproduction on rotations of 20 to 40 years for cordwood to be burned in brickyards, lime kilns, and brass mills or converted into charcoal for industrial uses has been systematically employed in the past and is still in operation in various parts of the country.

In the prairie region and other sections having a large percentage of agricultural land in comparison to forest soils, the markets for small hardwood material for posts or fuel are sufficiently good to make profitable their production in coppice stands. Often such stands may be established as plantations to be reproduced and handled thereafter under the coppice method.

The eucalypts which have been introduced into California can be handled successfully in coppice stands.

When sprouting species are grown for pulpwood, coppice may be an excellent method to employ. With many of our hardwood species that sprout vigorously, the sprouts remain healthy until sizes suitable for sawtimber have been attained. From this standpoint the coppice method with rotations of 60 to 90 years would often be feasible. The reason it is not employed to greater extent with such species is that stumps of these ages are likely to sprout poorly or not at all.

Redwood is one of the few native conifers that sprout prolifically and probably the only one for which management on a coppice method has been considered. At one time it was thought that this method might be feasible, but later studies indicate that only about 8 per cent of the cutover areas restock with redwood sprouts (Person and Hallin 1942). Scattered clumps of redwood sprouts undoubtedly will prove an acceptable part of the new crop, because of their

great resistance to decay, but the main reliance for regenerating redwood stands will be on seed rather than on sprouts.

Aspen in the northeast reproduces prolifically from root suckers which are capable of living through a rotation and producing excellent crops. Aspen stands can be successfully regenerated by the coppice method, clearcutting when 40 to 50 years of age. The new crop will consist mainly of root suckers.

On the whole with the increasing application of silviculture in the United States the coppice method will tend to be employed less and less, except under exceptional or particularly favoring conditions, some of which have been mentioned in the preceding paragraphs. The tendency in treating our hardwood forests will be toward rotations too long for complete stocking of an area with coppice regeneration. However, the excellent sprouting ability of many American species will result in a small percentage of sprouts in many stands reproduced by methods other than coppice. Such sprouts very frequently grow to good sawtimber size without being seriously, if at all, affected by decay.

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CHAPTER IX

THE COPPICE-WITH-STANDARDS METHOD

Definition. In this method of reproduction, either seedling trees or selected sprouts are maintained above a coppice forest as standards. Reproduction is largely from sprouts as in the coppice method, but the area is never cut entirely clear. The standards are left standing at the end of each coppice rotation. The method is also known as compound coppice.

Form of Forest Produced. Several age classes are found in compound coppice stands. The young coppice itself is all of one age and presents a uniform appearance. Above the coppice are standards belonging to several different age classes, each one of which is a multiple of the rotation age of the coppice. The form of stand produced is one of several stories, each evenaged by itself but combined to create an irregular stand.

Details of the Method. The coppice-with-standards method is most easily understood by taking ordinary coppice as the starting point and following step by step the development of a compound coppice stand. When the coppice reaches the end of the rotation it is not cut clear but certain trees or standards are carefully selected and retained, the balance of the coppice being cut. The sprouts that follow the cutting form a distinct story under and between the standards.

A second rotation of the coppice passes, and at its end standards are again selected from among the best trees in the coppice and the remainder are cut. Some of the standards left at the end of the first coppice rotation may be taken out, but the better ones are left. After this cutting three distinct age classes or stories are represented — the older standards now twice the age of the coppice rotation, the younger standards of an age equivalent to the coppice rotation, and finally the new generation of sprouts springing up from the recently cut coppice. This process may be continued through as many coppice rotations as desired, increasing by one for each succeeding cutting of the coppice the number of age classes occurring on the area. Eventually the older standards reach the age assigned for their rotation, which will be a multiple of the coppice rotation. When this occurs, the oldest age class of standards is cut at the same time that the coppice is harvested, and the poorest trees are

removed from the other classes of standards. From this point on, the number of age classes on the area remains constant. (See Figs. 39, 40, 41, and 42.) Where more than one species is reserved as standards, there may be a different rotation for the standards of each species.

Sprout reproduction is relied upon to maintain the coppice. This is possible because of the low rotation. The standards, when finally harvested, are usually too old to sprout. If a small area around the stump of a standard is not stocked the gap is filled by planting.

Since the standards live through several coppice rotations, the danger of their becoming infected with fungi is great, if they originate from sprouts. Standards of seedling origin are less liable to such injuries than trees of sprout origin; hence it is desirable that most of the standards have seedling origin. There may be a sufficient mixture of seedling reproduction starting naturally with each new crop of coppice. Indeed the presence of standards capable of furnishing seed tends to bring in more seedling reproduction than occurs in simple coppice stands. When natural seedlings of the right species are available, the standards should be selected from among them. If seedlings are lacking, it becomes necessary to make provision for new standards by planting seedling trees among the stools when the coppice is cut. Plants for this purpose should be large, strong transplant stock to compete with the sprouts. If the species planted reproduces vigorously by sprouts, the transplants after being set out can be cut back carefully to the ground level. One or more vigorous sprouts start and compete more successfully with the coppice sprouts than the original transplant could have done. If several sprouts arise the number should be reduced to one. Such sprouts, termed "seedling sprouts," have the rapid initial growth of true sprouts, combined with the relative hardiness against disease possessed by trees of seedling origin.

The standards and coppice may or may not be of the same species. In general, light-foliaged species are favored as standards, while trees capable of thriving under a partial cover are desirable in the coppice. The coppice furnishes cordwood and other products of smaller size, hence the species in the coppice must produce wood which has a value while still young. Standards grow until large enough for lumber and should be chosen for their ability to grow throughout several coppice rotations and for the value of their lumber yield. It is often desired to introduce a species not found on the site as a standard. A conifer of high timber-producing value may thus be employed as a standard over hardwood coppice.

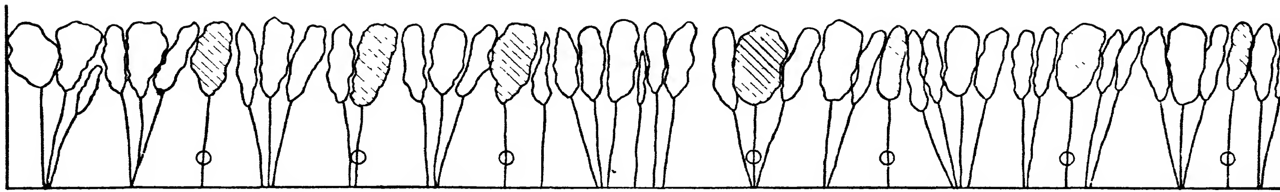

FIG. 39.

Coppice with standards. A coppice stand 20 years old ready to be cut clear except for selected standards which will be reserved to develop a coppice-with-standards stand. Note that trees of seedling origin have so far as possible been chosen as standards. The trees selected as standards are designated by circles.

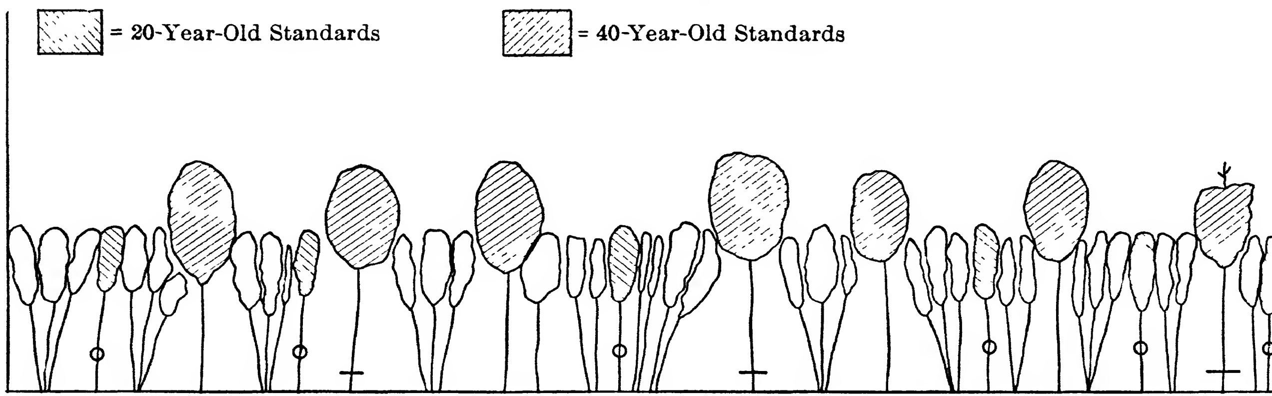

FIG. 40.

Same stand as in Figure 39, but 20 years later, at the end of a second coppice rotation. The coppice will now be cut clear, reserving as standards the trees designated by circles. Three of the 40-year-old standards (indicated by dashes) will be cut in the same operation as the coppice.

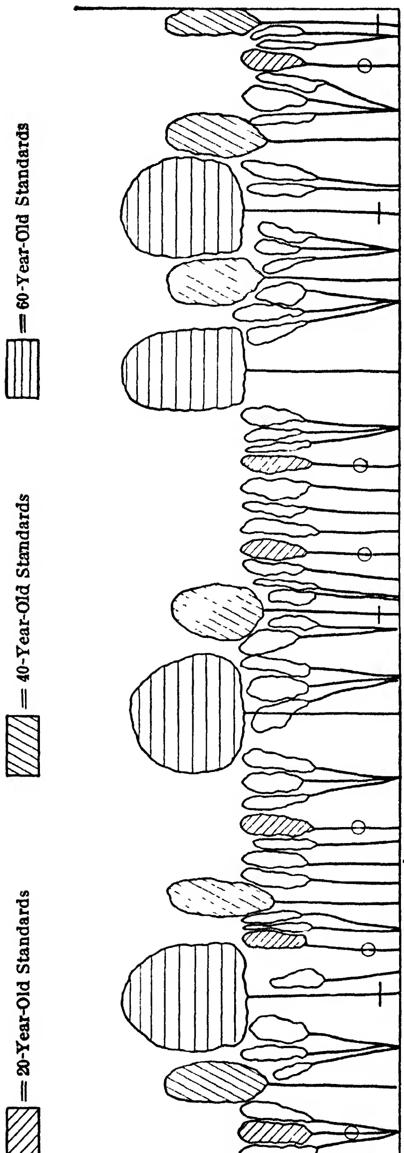

FIG. 41.

Same stand as in Figure 39, but 40 years later, at the end of a third coppice rotation. The coppice will be cut clear, reserving as standards the trees designated by circles. At the same time a thinning in the 2 older age classes of standards, removing the trees indicated by dashes, will be made.

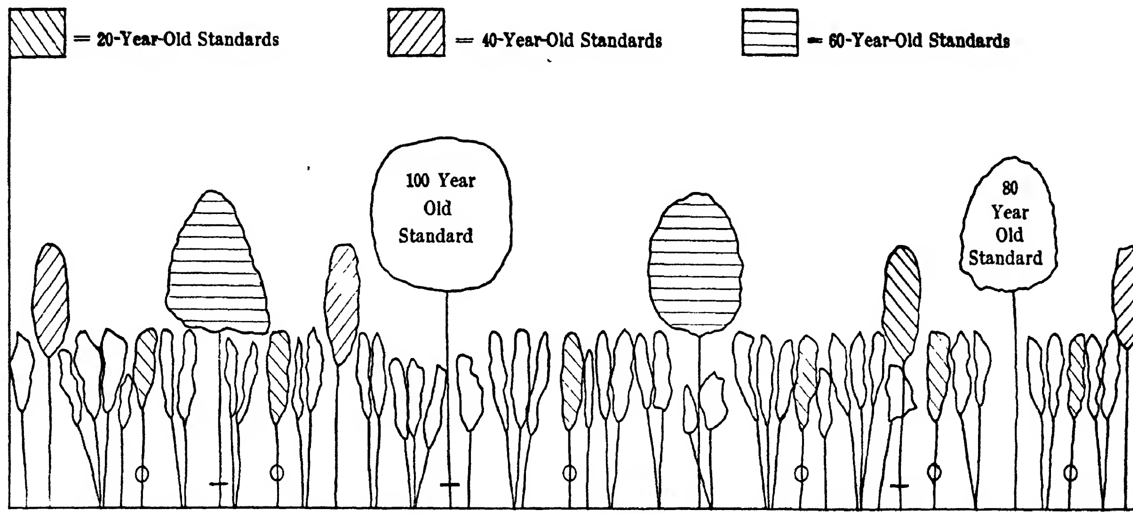

FIG. 42.

Same stand as in Figure 39, but at the end of 5 coppice rotations. Length of rotation for standards is 100 years. A complete series of standard age classes is now present. The coppice is ready to be cut together with all the 100-year-old standards. In addition a thinning is made in the other age classes of standards. Standards to be removed are indicated by dashes. Trees in the coppice to be reserved are designated by circles. The stand has an irregular or several-storied form midway between the evenaged and unevenaged forms.

Rotations for the coppice usually range from 20 years on the best soils to 40 years on poor soils, which are as long intervals as should ensue between cuttings among the trees in the various age classes of standards (Kittredge 1920). The coppice rotation may be as low as markets for the small products permit; but good standards cannot be produced unless the coppice is grown on a relatively long rotation and becomes high enough to provide standards with fairly clear boles. The rotation for the standards may be any multiple of the coppice rotation. Rarely would it be advisable to have such a rotation be longer than 4 or 5 times the length of the coppice rotation.

In selecting trees to be left as standards, the question arises as to how many should be left per acre. The answer is contingent upon the silvicultural habits of the species, particularly the spread of the crown, but primarily upon the relative extent to which the standards as contrasted to the coppice are to be favored.

Three forms of coppice with standards may be distinguished (Hamm 1896), depending on the relation between the standards and coppice.

1. Compound coppice approaching simple coppice, where the overwood of standards is distributed by single trees of only a few age classes and occupies a small part of the area. Firewood is the chief product.

2. Normal compound coppice, in which the sprouts and the standards are of equal importance and both cordwood and timber are produced in quantity.

3. Compound coppice approaching high forest, in which the standards occupy a large part of the area, usually in groups, and the coppice possesses the importance only of a soil-protecting cover. Timber is the principal product.

These 3 forms indicate the variations in mixtures of coppice and standards that are available in passing from a coppice stand to high forest.

The area covered by the spread of the crowns is the basis for judging the part of the stand occupied by the standards. The percentage of the total area allotted to the standards should be decided upon before any cuttings are made.

After the portion of the total area to be devoted to standards has been determined, it should be apportioned equally among the several age classes of standards which will be present. If, for example, 0.5 of the area is allotted to standards and there are 5 age classes of standards on a rotation of 120 years, 0.1 of the area should be

occupied by the standards of each age. Each age class of standards occupies the same area as it increases in age throughout the rotation. As a necessary corollary each age class of standards must contain more trees when first established than at the end of the rotation, because each individual tree occupies more space with increase in

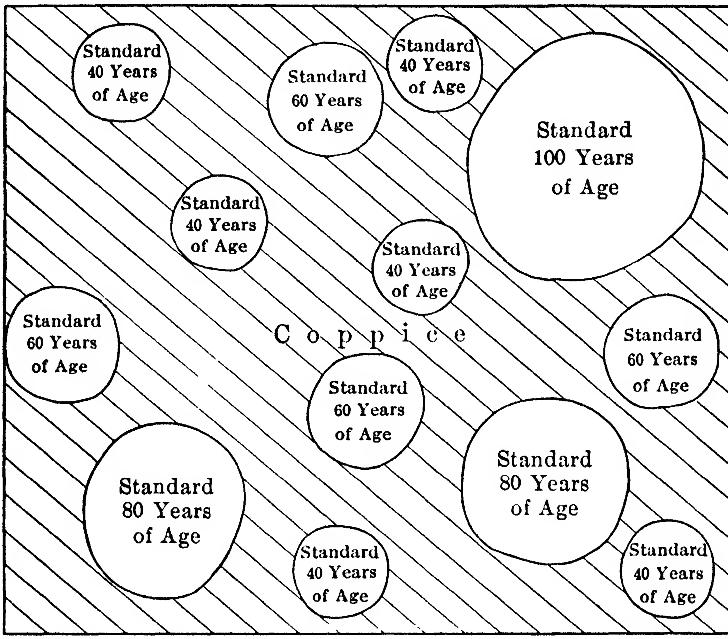

FIG. 43.

An illustration of the distribution of the area between the coppice and each age class of the standards. The stand is assumed to be at the end of a 20-year coppice rotation just before the cutting. Rotation for the standards is 100 years. In this diagram 0.6 of the total area is in coppice. The balance, 0.4 of the total area, is equally distributed between the 40-, 60-, 80-, and 100-year-old standards. The new standards, 20 years in age, to be left after the cutting of the coppice are not shown but are included in the area allotted to the coppice. The 100-year-old standards will be cut along with the coppice, and the new 20-year-old standards will occupy the area otherwise lost to the standard classes by cutting the 100-year-old trees.

age. In order to keep the area occupied by standards of a given age approximately constant, it is necessary to reduce their number occasionally (see Fig. 43).

This is done at the time the coppice is cut clear. Where standards are in dense groups overtopped, intermediate or codominant trees may be cut in thinning without decreasing the area filled by the age class, but in addition other standards must be cut, which will actually reduce temporarily the area occupied by that class.

The relative number of standards at different ages must be worked out for each species and situation. The illustration in Table VI, for oak in a European forest, is cited by Graves (1911):

TABLE VI

Number of Standards	
100 years old	1
80 years old	2
60 years old	3
40 years old	12
20 years old	20

A uniform distribution of standards over the area need not be attempted. They may be left singly, wherever desirable trees for standards occur among the coppice, or in groups. The group plan has especial merit for conifers, introduced artificially, in producing clearer boles.

The isolated position of the standards with full light from all sides, particularly for a few years after the periodic cutting of the coppice, often results in the formation of epicormic branches on trees which have inadequate crown development. Formation of epicormic branches occurs more frequently on broadleaved trees although coniferous trees are by no means immune. Pruning is not an efficacious method of control since resprouting takes place and repeated pruning would be required to keep the stem free of epicormic branches.

A better method of control is to prevent the formation of epicormic branches. These branches arise principally from dormant buds. When there is an equilibrium between the actively functioning surface of the roots and that of the foliage in the crown, dormant buds do not develop into epicormic branches. A variety of causes may upset this equilibrium and cause dormant buds to emerge. Any shock to the tree may have this result. Development of epicormic branches has been noted especially after heavy opening of a stand by cutting. The explanation usually given is that the changed conditions of greater light and heat have stimulated the dormant buds. On the other hand development of epicormic branches can frequently be seen in dense stands before any cutting has been made. Here the reduction of foliage area without a corresponding reduction of root capacity usually is assigned as the cause.

If a round, full crown adequate in depth and width for the size and age of the tree is maintained, there should be no development of epicormic branches even after heavy cuttings. This leads to the

conclusion that control against such defects may best be secured by early and frequent thinnings of reasonable severity for the species.

Advantages and Disadvantages of the Method. Coppice with standards occupies a position intermediate between simple coppice and the high-forest methods, though nearer to the former. It shares in a lesser degree the advantages and disadvantages of coppice as contrasted with high forest.

Advantages. 1. Secures the benefit of rapid growth of individual trees in an open stand without danger of exposing the soil. The standards grow in isolation during a large part of their life, while the coppice protects the site. Equally rapid growth of individual trees cannot be obtained under high-forest methods without exposure of the site or expensive underplanting. This advantage is greatest with species whose timber value per thousand feet, board measure, is appreciably enhanced as diameter increases.

2. Does not require so large a growing stock or financial investment as do high-forest methods.

3. Yields a relatively high net return on the investment owing to the amount of capital invested and sometimes to high prices received for material of large size. The illustration in Table VII, taken from experience in Baden (Hamm 1896), will illustrate the effects of advantages 2 and 3.

TABLE VII

	Annual Cut per Acre, cu. ft.	*On a Growing Stock of, cu. ft.*	*Volume Growth, per cent*
High forest	62.86	3461	1.82
Compound coppice	65.68	1642	4.00
Simple coppice	58.62	600	9.76

4. Furnishes excellent protection both to the site and to the stand against injuries by frost, heat, and wind. In these respects the method resembles selection. Since the younger standards are always on the ground, a partial cover is constantly maintained, and the coppice springing up quickly after each cutting affords additional protection. The standards are windfirm, having been gradually accustomed to greater and greater exposure, while by their cover they protect the young coppice from frost, excessive drought, and evaporation.

5. Is esthetically a desirable method. Although less irregular in appearance than a selection forest, a compound-coppice stand permits development of fine individual trees, contains several age classes at

all stages and does not produce the regular form which is a consequence of certain other methods.

6. As compared with simple coppice, compound coppice has the advantage of:

(*a*) Abundant seed production by the standards, thus providing for an excellent representation of seedling trees among the coppice sprouts.

(*b*) Permitting the production of considerable sawtimber and with a larger growing stock providing more adequately for future demands though far inferior to high forest in this respect.

Disadvantages. 1. Requires a high degree of skill in the application of silviculture and in the regulation of the amount to be cut. This comes from the complicated form of stand which must be maintained and from the fact that in the management of the standards more consideration is given the requirements of the individual tree than under most of the other methods. The same disadvantage applies to the selection method.

2. Although timber is likely to be the principal product, yet, just as with simple coppice, there must be a market for cordwood or other low-grade products.

3. The standards, being grown in relatively open position, may have a poor tree form, short clear length, and large branching top. On poor soils this is more to be feared than on deep, moist soils, and compound coppice should not be used there. This defect can be remedied to some extent by pruning. With hardwood timber, comparatively clear wood of wide dimension may be more desirable than trees of smaller size entirely clear of knots.

4. Makes relatively high demands on the fertility of the soil, though not so exacting in this respect as simple coppice.

Application of the Method. Compound coppice is of ancient origin in Europe, the reserving of standards having been tried before 1600. The method fell into disfavor because of the intensive silvicultural and regulation practice necessitated.

In North America silviculture has not been practiced long enough to furnish complete examples of such a complicated reproduction method.

There is good reason to believe that it will be employed throughout much the same general regions as simple coppice and be applied by private owners rather than on public forests, for reasons similar to those given on page 186.

For the production of white oak, white ash, and yellowpoplar in stands of mixed hardwoods, and for the introduction of a small

mixture of conifers into stands of hardwood coppice, compound coppice is likely to find favor in the future. The owner of a small area of woodland who desires to grow a little large timber in addition to fuel for the home will find the method useful.

Owing to the protection from frost afforded the sprouts by the standards, compound coppice can be used at higher elevations than simple coppice. It should be confined to soils of good or at least average quality.

Conversion of Coppice and Coppice with Standards into High Forest. In European countries, particularly France, the tendency during the last few decades has been toward the conversion of coppice and coppice-with-standards forests into high forests. The principal cause for this change in method is the relatively low prices prevailing for fuel wood and other products of small trees.

Various methods have been used to effect conversion (Champion 1922, Troup 1928). The subject is of interest for America since many of our present coppice stands should be converted to high forest. Quite a variety of practice has developed, but that of greatest interest for this country may be summarized under the following two headings:

1. *Conversion by cutting clear part or all of the coppice stand and planting the desired species.* Clearcutting and replanting with a conifer comprise exactly the method which has been employed in a number of instances in the eastern United States (Richards 1917). It is interesting to note that experience abroad indicates that the method requires too great expenditures for cutting back coppice shoots in order to protect the planted trees from suppression. Local experience has shown that the necessary cultural operations (see Chapter X) may be more expensive than the planting costs. By planting relatively few trees, widely spaced, and freeing only these trees, the costs per acre of the conversion can be reduced. Later by means of proper thinning the planted trees can be developed into a completely stocked stand. Probably a spacing from 10 by 10 to 20 by 20 feet will be found the best to adopt in applying this idea.

2. *Conversion by lengthening the rotation to such ages* (70 *years or more*) *that the coppice stools when cut will fail to sprout and then, by reproduction cuttings of the shelterwood type, establishing seedling regeneration.* The procedure consists in thinning the existing coppice stands at repeated intervals, saving the more promising stems.

Toward the end of the rotation, shelterwood cuttings should be made. This will establish an abundant seedling reproduction. If a few of the old stumps sprout, the sprouts can later be removed in

cleanings or in the thinnings. This method is more promising for present-day conditions than the first one.

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or are likely to overtop them. The terms "assistance cutting," "disengagement cutting," "release cutting," and "weeding" have been employed as synonymous. Of these, weeding is considered the most desirable. Release cutting is not a synonym for cleaning but has a broader meaning and includes the operations covered under both cleanings and liberation cuttings.

The term "weeding" is preferred to "cleaning" by some foresters, because in their opinion it is more descriptive of the operation practiced in the forest, which they are accustomed to consider synonymous with the work of weeding in agricultural practice. As a matter of fact, a cleaning operation should not be considered synonymous with weeding either agricultural crops or forest-tree nursery stock. Weeding removes all plants competing with the crop species. It makes no difference whether these competing plants overtop or threaten to overtop the crop or whether they simply crowd from the side or form a mat under the crop species. In weeding, all these plants should be removed. In a cleaning only the plants overtopping or threatening to overtop the crop species would be removed. In Indian silviculture both weeding and cleaning are recognized, each having a distinct meaning of its own. Champion (1938, p. 251) defines the two terms as follows:

Weeding: "The removal or cutting back of competing growth in seedling crops."

Cleaning: "The removal or topping of inferior individuals or species from a sapling crop, i.e., a crop over 3 feet high."

In discussing the use of both operations, it is brought out that the principal material removed in weeding consists of herbaceous weeds and that the operation, outside of its application in the forest nurseries, is employed after direct seeding and in very young plantations and stands of naturally reproduced small seedlings.

The use of both words with recognition of the difference between weeding and cleaning would be better practice than employing them as synonymous.

Liberation cutting. A cutting made in a young stand, not past the sapling stage, for the purpose of freeing the young growth from older individuals (wolf trees) which are overtopping. These older individuals may be either of good species but of the "wolf tree" character or else of species less desirable than the overtopped young growth.

Thinning. A cutting made in an immature stand for the purpose of increasing the rate of growth of the trees that remain and the total production of the stand; removing mostly trees not in a dominant

position, in contrast to cleanings, liberation cuttings, and improvement cuttings which characteristically take out trees overtopping better individuals.

Improvement cutting. A cutting made in a stand past the sapling stage for the purpose of improving the composition and character by removing trees of undesirable species, form, and condition occupying dominant positions in the main crown canopy.

Salvage cutting. A cutting made for the purpose of removing trees killed or damaged by various injurious agencies, of which fungi, insects, and fire are the most serious.

Pruning. A cutting that removes branches from standing trees for the purpose of increasing the quality of the final product.

A detailed discussion of the various intermediate cuttings will be found in the succeeding pages.

During the life of a stand there may or may not be need of applying all kinds of intermediate cuttings; but if applied they are likely to occur as explained in Table VIII.

TABLE VIII

Kind of cutting	*Time of application*	*Remarks*
Cleaning	1st to approximately the 20th year	Frequently unnecessary
Liberation cutting	1st to approximately the 20th year	Frequently unnecessary
Thinning	Early life to beginning of period of regeneration	Needed in all fully stocked stands
Improvement cutting	20th year to beginning of period of regeneration	Usually required in mixed stands previously unmanaged
Salvage cutting	20th year to beginning of period of regeneration	Used only in case of injury to the stand
Pruning	1st quarter or half of the rotation	Advisable only in special cases

Application in Evenaged versus Unevenaged Stands. In unevenaged stands the details of applying the principles are different from those employed in evenaged stands. The practice in an evenaged stand, being simpler, will serve as the basis in discussing the different kinds of intermediate cuttings, except when otherwise specifically stated. In the evenaged stand each kind of intermediate cutting can be applied as a separate operation, conducted independently of reproduction cuttings or other kinds of intermediate cuttings, and extending more or less uniformly over the whole area. In the unevenaged stand, since the period of regeneration is coextensive with the

rotation there may appear to be no opportunity for intermediate cuttings. But reproduction is not in progress continuously in all parts of the stand. Each year certain small patches scattered through the stand are reproduced. When reproduction is once established on these patches, the period of regeneration closes as far as they are concerned. Any cuttings made in these small areas during the remainder of the rotation will be in the nature of intermediate cuttings. With many small areas of different-aged trees within the same stand, there may be need for all kinds of intermediate cuttings simultaneously and in addition to the reproduction cuttings which are annually or periodically made. Reproduction and intermediate cuttings within the same stand are thus combined in one operation, although each class of cutting will be on a different portion of the area.

Cleanings, thinnings, improvement cuttings, and salvage cuttings are the principal kinds of intermediate cuttings likely to be made in unevenaged stands. Liberation cuttings find less frequent application.

Cleanings. Cleanings are cuttings made in young stands (not past the sapling stage) for the purpose of freeing the more promising trees from other individuals of similar age but of undesirable form

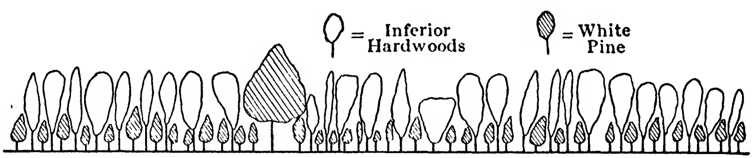

FIG. 44.

A stand of white pine and mixed hardwoods in need of a cleaning. The hardwoods and the large pine, which is too limby to make good timber, should be cut. See Figure 45.

FIG. 45.

Same stand as in Figure 44, but immediately after the cleaning has been made. This cleaning was made early enough in life so that the pine had not yet been deformed by the overtopping hardwoods. The operation results in transforming the stand from one dominated by inferior hardwoods to pure pine.

or species which are overtopping or are likely to overtop the former trees.

The principal purpose is to regulate the mixture to the advantage of the better species in the stand. Oftentimes the composition of the stand is radically changed as a result of these cuttings (see Figs.

44 and 45). In young growth composed entirely of one species, no question of regulating the mixture arises and cleanings are not so essential. If cleanings are made at all in such stands, the object is to remove trees of poorer form than those that are being overtopped.

Cleanings are the first cuttings made in a new stand after its establishment and should take place as soon as the individuals which need help are threatened with injury.

In semitropical and tropical climates cleanings may be needed the first year the new crop is established. Indeed, several cleanings in a single year often are required to control the luxuriant vegetation which otherwise would choke out the crop trees.

In temperate climates cleanings usually are first needed around the third to the tenth year. These should be made as soon as needed, because the cost is less if the material cut is small, and also because overtopping trees may very quickly do irreparable injury to desirable trees.

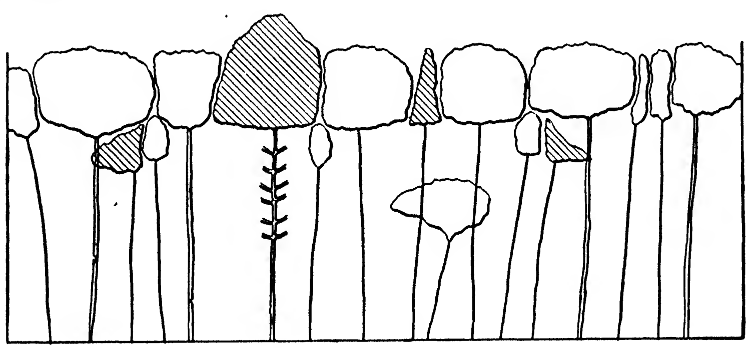

Fig. 46.

The same stand as in Figure 44. The relative position of the pine and hardwoods 40 years later than the time of Figure 44, provided no cleaning is made. Note that only one pine, namely the one that had a start over the hardwoods, is now in a dominant position. The yield of this stand is principally cordwood instead of pine lumber, which could have been the chief product if a cleaning had been made. The pines are indicated by cross-hatching.

For a few years the shade afforded by undesirable species may be of benefit to the small seedlings of the more valuable species as a protective cover. The situation soon changes, and instead of being a benefit the overtopping individuals hinder the growth and, if allowed to remain, may cause the death of the better trees (see Fig. 46). This result may be due to the direct competition between the trees and also, in some cases, to the mechanical effect of the overtopping tree in whipping the top branches and stems of the desirable tree. In this way buds may be removed and growth arrested (Spaeth

1922). Sometimes one cleaning is sufficient to regulate the mixture. More often 2 to 4 cuttings made at intervals of 3 to 5 years will be required to accomplish the purpose, especially if the trees removed possess sprouting ability. Trees taken out in cleanings belong to all four crown classes but principally to the dominant and codominant classes (for definitions see page 217). Their removal creates small gaps in the upper canopy. Any openings of this sort are quickly filled by the better trees coming up from beneath or expanding their crowns.

Specifically the material that is to be removed in cleanings consists of:

1. Trees and other plants of undesirable species.
2. Sprouts of a desirable species, if seedlings of the same species can thereby be freed.
3. Advance growth of a desirable species, if inferior in form to another individual of the same species which might thereby be freed. Scattered trees a few years older than the remainder of the stand, because of their comparative freedom from side crowding, have rather branchy crowns and may develop into trees of the best type. However, the qualifying statement should be made that advance growth is often desirable.
4. Shrubs and vines. Climbing vines, both by overtopping and by mechanically constricting and deforming trees, often prove as serious as competing tree species.

In making a cleaning the trees to be removed may be either cut, girdled, or poisoned. On the whole, because of the small size of the stems to be dealt with, cutting is the method most commonly used. The average stand when it first needs cleaning will be composed of stems less than 2 inches in diameter. These can be cut more economically than they can be girdled or poisoned. Where material above 2 inches must be treated either poisoning or girdling is possible. Consideration of these methods will be found on page 209.

In cutting, the common practice is to sever the stem at any convenient height well below the top of the tree which is being released. The principle involved is to cut back the undesired tree sufficiently so that subsequent growth will not again enable it to pass and overtop the released tree. Since the crop trees are often only a foot to a few feet tall, it is evident that cutting back right to the ground will not always prevent further overtopping and a second cleaning. With species that do not sprout the problem is simple. Once they are cut off close to the ground their competition is permanently removed. On the other hand, with trees that possess sprouting ability, strong

sprouts shoot up from the stump and within a year after the cutting may again overtop the valuable species. In fact the competition of the undesirable species may be more oppressive than before the cutting. Sometimes more than one cleaning in the same year may be required for adequate release of the crop trees.

If a procedure could be found for preventing resprouting of undesirable trees cut or otherwise treated, the effectiveness of the cleaning would be improved and the necessity for a second operation at any later time might be eliminated. Several attempts have been made to find a treatment to prevent sprouting, but no practical method generally effective has been found. The old idea that cutting in late summer would prevent sprouting has not proved true. Undoubtedly the vigor of sprouting is influenced by the season in which the work is done. By cutting in the right season, the height of the new sprout crop may be lowered and thereby severe competition with the released trees be delayed or rendered less intensive.

Buell (1940) reports that midsummer fellings of small dogwood (1 inch) produced sprout clumps 2½ feet shorter and 1½ feet narrower on the average, 3 years after cutting, than did winter fellings. The tallest sprouts were obtained from fellings made in March. The height above ground at which the stems are cut was found to have an important influence on the sprouting of hop-hornbeam (Diller 1935). Eighty-three per cent of the trees cut at the ground level failed to sprout, while only approximately 12 per cent of those cut at heights of 12 to 36 inches failed to sprout. The reason advanced is that sprouts originate on hornbeam only from the main stem and not from the roots, a point which does not hold for all species.

In mixed stands of bear oak and other hardwoods underplanted with pine, experiments have been tried of cutting the hardwoods with the exception of one sprout on a stool (Illick 1919). The single sprout left retarded the development of a heavy sprout reproduction following the cleaning; on the whole the pine was left in better condition where this plan was used than where similar areas were cut clean. Where tried elsewhere, this method has not always proved successful. It may be that with light-demanding species and on the drier soils the procedure has its greatest usefulness.

Buell (1943) working with southern Applachian hardwoods found that new sprouts were no higher when all stems in a clump were cut than when some of the stems were left standing.

Climbing vines may be cut, but the best method to eliminate them is to dig or pull up by the roots.

The relative heights and rate of growth of the trees to be favored

and those to be cut must be considered in deciding upon the best method of making the cleaning. In fact, accurate knowledge of the relative height growth of the species associated in the stand is essential in planning and executing a successful cleaning, since the object of the operation is to keep the favored trees above those less desirable.

A cardinal principle in making cleanings is never to cut more than is necessary to accomplish the purpose sought. Undesirable species should be cut only if they threaten the health of better trees. Otherwise, large and possibly permanent openings may be created because some of the undesirable trees are frequently needed, during the first part of the rotation, to complete the density of a stand partially stocked with valuable species. The item of cost is an additional factor rendering it advisable to restrict the amount of material removed in cleanings to the minimum. It is better practice to make several light cleanings as needed at intervals of 3 or 4 years rather than a single heavy cleaning.

The small size of the material taken out makes a cleaning an item of immediate expense, returning a profit only at some future time through an increased yield of the valuable species freed. In exceptionally open-grown stands where the need for cleanings develops late, if the material removed is large enough for cordwood a cleaning will yield a small profit. Actual costs of making cleanings will range from a fraction of a day's labor per acre up to several days. Usually the time required to clean an acre will fall between one half and one day. The increased net returns to be obtained as a result of the cleanings should always be investigated before such cuttings are made. Cleanings usually can be justified, where there is a wide difference in value of final product between the trees freed and those cut, and where the yield of the valuable species will be greatly reduced if nothing is done. Plantations of conifers interfered with by hardwood growth furnish an excellent illustration of this principle.

A variety of tools will be found useful in making cleanings. The size of the material, method of making the cuttings, and available room for using various tools should determine the selection. The axe is the best tool where the material is large enough for cordwood. For smaller material, bushhooks, billhooks, longhandled pruning shears, and heavy knives of the machete type can be employed to advantage. Cook (1940) recommends an ordinary sickle, with 6 inches broken off the end of the blade, for cutting trees 2 inches or less in diameter. Other tools useful in making cleanings are pruning

shears, both the light one-hand type commonly used in horticultural pruning and the two-hand type. Shears with handles from 20 to 36 inches can be used to advantage in cutting stems up to at least 2 inches in diameter.

Cleanings can be made at any time of year, the operation often being fitted in to occupy odd hours. Some men prefer to do the work when the leaves of the broadleaved trees have fallen, so that conifers underneath can easily be seen. Others prefer to operate with the leaves on, in spite of the fact that the work is slowed up thereby, so that competition between stems can be more accurately gauged. With species whose tops are easily broken when frozen and are susceptible to ice and snow injury, spring or early summer is preferable to the fall and winter.

Liberation Cuttings. Liberation cuttings are those made in a young stand, not past the sapling stage, for the purpose of freeing the young growth from older individuals which are overtopping. Liberation cuttings are made during the same period in the life of the stand as cleanings but differ in that they take out trees larger and older than the young stand whereas cleanings remove trees of approximately the same age as those freed. The trees removed in a liberation cutting are either individuals which were left standing when the previous stand was harvested, or (on open lands which have been reforested) trees that started by natural means on the area long before it was reforested.

Trees that have developed with abundant room on open lands are short and stocky with short clear length and a wide spreading crown — in other words, wolf trees. Those left from previous cuttings, while less spreading in habit, are likely to be cull trees or inferior species which it was unprofitable to cut. Trees of this sort should not be confused with thrifty reserves, which may have been left in the reproduction cuttings to grow through a second rotation.

Liberation cuttings should be made as early in the life of the young stand as possible. The shade and protection of these large trees soon cease to be beneficial. If they are left too long, all the overtopped young trees may die. Less damage is caused to the young growth and less expense is involved in the removal of the large trees if the operation is accomplished when the young stand is only a foot or two in height. Where the operation has been delayed until the young trees are pressing with their crowns against the crowns of the overtopping trees and bending aside, the result of the cutting is less satisfactory. (See Figs. 47 and 48.) It is possible that gaps large enough to require filling by artificial means may be created by the

competition of the large trees and the damage inflicted in their removal.

One method of making liberation cuttings is to fell the trees and utilize whatever merchantable material they contain. Care must be

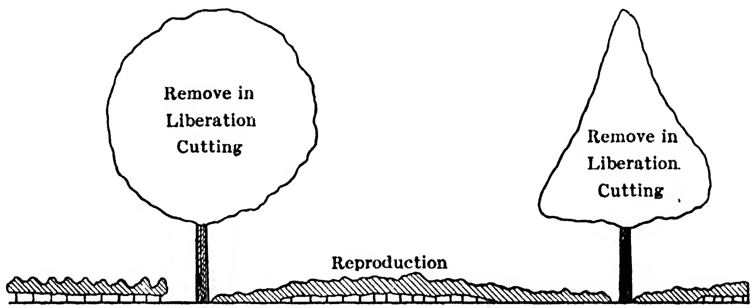

FIG. 47.

A stand in need of a liberation cutting. The young trees as yet have not been seriously affected by the large overtopping trees.

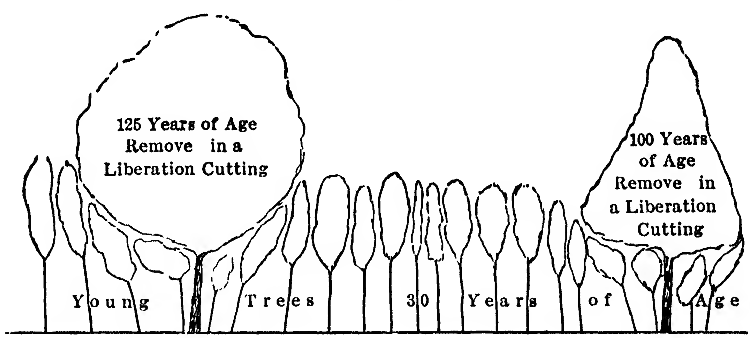

FIG. 48.

A stand in need of a liberation cutting. The cutting should have been made 10 years ago before the young trees under the old ones had been deformed.

taken to cut up the tops, if not utilized, and place them in such position as not to interfere with the young growth.

Another method of killing undesirable trees is by girdling* their stems and leaving the trees standing. Cutting a ring around the trunk through the bark and well into the sapwood ordinarily will cause death of the tree within 3 years and sometimes sooner. The competition afforded by the girdled trees is lessened appreciably the first season after girdling, even though they may not die that season.

* What is said here concerning girdling and poisoning has application not only in making liberation cuttings but also in cleaning and improvement cutting.

To be effective in killing the tree promptly, the ring must be cut completely through the bark at every point on its circumference and well into the sapwood. Some species are harder to kill by girdling than others, and the details of performing the operation should be varied to suit the conditions. Several methods of girdling are quite generally recognized (Westveld 1942) as follows:

Notching, in which a notched ring is cut around the tree through the bark and ½ to 2 inches deep into the wood.

Single-hacking, in which a single line of overlapping axe cuts is made completely around the tree. The cuts go through the bark and into the wood.

Double-hacking, in which a line of chips is removed completely around the tree by the process of striking two downward blows one about 3 inches above the other, thereby enabling a chip to be thrown or pried out.

Peeling, in which the bark is stripped off in a band at least 8 inches wide completely around the tree.

Notching is expensive but effective and should be used on trees difficult to girdle properly, such as those with infolding bark. Single-hacking is relatively cheap and if well done accomplishes the purpose of killing the trees, but careless work is difficult to discover until too late because no chips are thrown out. Double-hacking is likely to secure better results than single-hacking, if done by unskilled labor, and is easier than notching because the axe strokes are all downward rather than partly horizontal or upward. Peeling can be done very cheaply in the spring and early summer when bark strips off easily.

Peeling has a further advantage when preventing the girdled trees from sprouting is important. This is sometimes, though not always, essential. Sprouting of girdled trees is made possible by the reserve food supply in the roots. If this food is allowed to pass up the tree into the crown, as it would be if the girdling is restricted to bark peeling, sprouts will not be immediately developed below the girdle. Since no food can now pass downward from the crown to the roots, because a ring of bark has been peeled, the roots get no more food and finally die. Their death is followed by the death of the top.

The tools used in girdling are principally axes, but for peeling a draw shave is more effective. Cuno (1936) suggested the use of a special axe with concave cutting edge and wide blade, enabling the operator to girdle more circumference with each blow. Chain saws have also been tried as girdling tools and have been recommended as cheaper than notching (Liming 1941). A built-up chain saw can be developed to cut a ring an inch wide through the bark and into the

cambium. Chain saws as yet cannot be purchased on the market but must be specially built.

For large trees, girdling is cheaper than felling, especially if there is much lopping of tops to be done, but for small ones felling is usually cheaper. The line probably comes at about 5 inches, trees from this size up being handled by girdling more cheaply than by felling. Bull and Chapman (1935) estimate felling to be 1½ to 9 times as expensive as girdling. They also consider single-hacking to be the cheapest method of girdling, double-hacking requiring twice and notching 4 to 5 times as much time as single-hacking. Churchill (1927) found that the cost of girdling hardwoods in northern New York, to free overtopped softwoods, was about ⅓ cent per tree released, representing an investment of approximately $1.30 per acre or 3½ to 7 cents per cord of pulpwood finally produced.

The advantage of girdling over felling in addition to its cheapness is avoidance of damage to the young growth in felling. As the trees decay and fall to pieces over the course of several years, some injury may be done to the young growth but far less than that caused by felling the trees. Furthermore, the gradual removal of the overhead cover as the girdled trees die protects the young growth from injury due to sudden exposure.

A third method of treating undesirable trees is to kill them by poisoning. The best way is to introduce a solution of sodium arsenite into the tree. A series of slanting cuts is made through the bark into the sapwood in a ring encircling the tree, and the poisonous solution is poured into them. In order to lower the costs of the work, a special tool has been designed by Cope and Spaeth (1931), which in one operation makes the incision in the tree and pours the poison solution into the cut.

Pessin (1942) developed a method of placing sodium arsenite in holes bored or punched in the stem or roots of the tree with a special patented punch mounted on an axe head. One hole is enough for a 3-inch tree and 2 for a 5-inch tree. The holes are filled with sodium arsenite solution, which is soon absorbed by the tree with little chance for animals to be poisoned. Cost was estimated at less than 1 cent per tree. The method is advised for killing small oaks 2 to 4 inches in diameter overtopping longleaf pine.

Pearson (1937), in treating malformed ponderosa pine trees, bored augur holes 4 to 5 inches deep, pointed tangentially as far as practical and inclined at a 45° angle, and filled the holes with sodium arsenite solution. Two to four holes were needed on trees 5 to 12 inches in diameter. The holes should be spaced about 8 inches apart

and on big trees refilled with solution 15 minutes after the first application. The cost was estimated at 6 cents per tree.

Experiments were conducted by MacKinney and Korstian (1932) on the relative effectiveness and costs of felling, girdling, and poisoning the hardwood associates of loblolly pine. Their conclusions were that poisoning was the best method. Costs were highest for felling. Poisoned trees did not sprout so freely or so vigorously as those girdled or felled. This advantage, namely the reduction of sprouting, may be a most important one in favor of poisoning. Some poisoned trees do not sprout at all; in others, sprouting is little affected. This phase of the subject needs further investigation to develop, if possible, practical methods that can be relied upon to prevent sprouting. Cope and Spaeth (1931) found in New York State that poisoning done during the period from August to December was the most effective in preventing sprouting.

Though poisoning has already proved an effective method, it has not as yet been employed so extensively as felling and girdling for killing undesirable trees. One reason for this is the danger to the operators in handling the poison and the probability of killing domestic animals and wildlife (Cook 1944). Another objection is the cost which in many cases is higher than for girdling. If Pessin's method proves as cheap and effective in other forest types as in longleaf pine, the use of poisoning is likely to be increased. Poisoning has the same advantage as girdling in that the dead trees go to pieces slowly and cause very little injury to the released trees.

Whether an immediate money return can be secured from a liberation cutting cannot be predicted without a careful inspection of the overtopping trees and the difficulties attending their removal. Cordwood of good size is ordinarily one of the chief products, and some of the trees may contain one or more logs merchantable for lumber. The expense of cutting up the branchy trees and bringing together the logs and wood sparsely scattered over an area occupied by young growth is so high as seriously to cut into the revenue received from the logs and wood. Usually liberation cuttings will involve a present expenditure. Unless felling and taking out the merchantable material will at least pay all expenses of the work, girdling or poisoning should be employed. Such operations, although involving a small money outlay, will often be found advisable on account of increased future yield.

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CHAPTER XI

THINNINGS

Cuttings made in immature stands for the purpose of increasing the rate of growth of the trees that remain and the total production of the stand are termed thinnings. They remove mostly trees not in a dominant position, in contrast to cleanings, liberation cuttings, and improvement cuttings, which characteristically take out trees overtopping better individuals. Thinnings are intermediate cuttings, started after the necessary cleanings or improvement cuttings have been completed and removing living trees selected from among the less promising individuals of approximately the same age as those left. A point apparently not well understood is that thinning in the technical sense applies to a specific type of cutting made either in an evenaged stand or within one of the many evenaged groups that make up the age arrangement of practically all unevenaged stands. Loose usage of the word "thinning" to cover almost any kind of a cutting short of one which removes all trees is not technically correct.

Natural Development of the Stand. The theory of making thinnings finds its basis in the natural process of development of the stand. The average stand starts life with a relatively large number (usually expressed in the thousands or even tens of thousands) of trees per acre. Toward the end of its life, when it is ready for the reproduction cuttings, the number has been reduced to a few hundred trees per acre, frequently less than 100. (See Fig. 49.)

Ruthless competition for light, moisture, and nourishment has accomplished this diminution in numbers. The individual trees that survive are well pruned of branches and often contain a high percentage of clear lumber. The struggle for existence usually is so fierce as to reduce the growth and the vigor of all the trees in the stand although not uniformly in all individuals. The competition between the trees is well expressed by the changes in relative position in the crown cover which are in constant progress. As the weaker trees are crowded by their associates their crowns are restricted and forced out of the normal shape, and finally they are overtopped and ultimately die. It is a steady progression downward which only the strongest are able to escape. This process is technically known as a

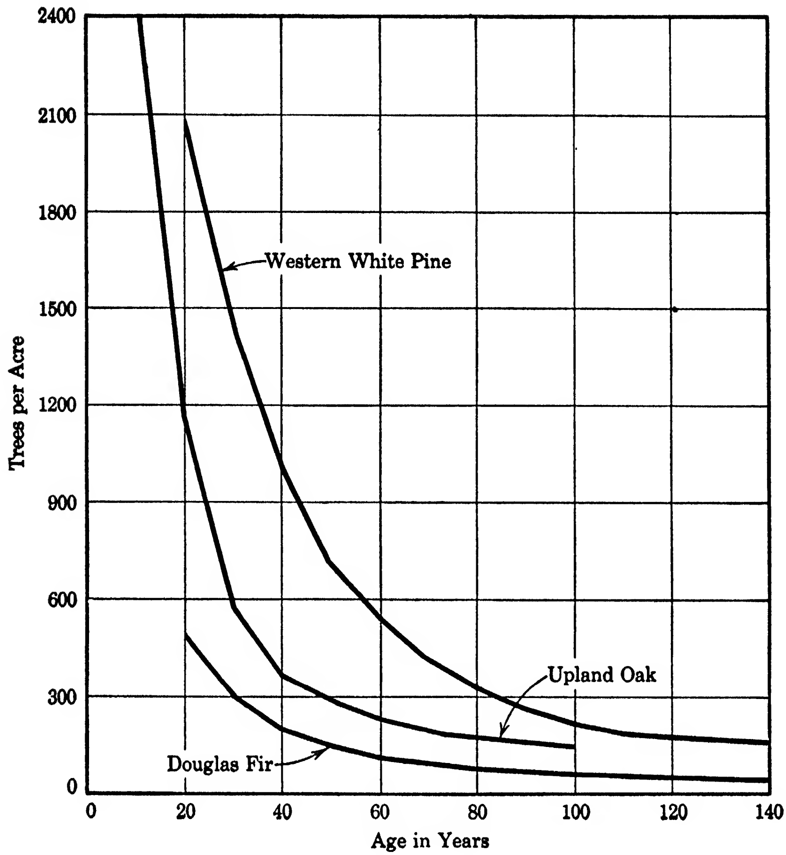

FIG. 49.

Curves showing the reduction in number of trees per acre, due to natural causes, with increase in age for stands of western white pine,[1] upland oak,[2] and Douglas-fir[3] on soils of best site quality for the respective species.

[1] Based on data for site index, 80 feet at 50 years, from p. 19, *U. S. Dept. Agr. Tech. Bul.* 323, entitled "Second-growth yield, stand and volume tables for the western white pine type."

[2] Based on data for site index, 80 feet at 50 years, from p. 18, *U. S. Dept. Agr. Tech. Bul.* 560, entitled "Yield, stand and volume tables for evenaged upland oak forests."

[3] Based on data for site index, 210 feet at 100 years, from p. 14, *U. S. Dept. Agr. Tech. Bul.* 201, entitled "The yield of Douglas fir in the Pacific Northwest."

differentiation into crown classes; four standard crown classes are recognized (see Figs. 50 and 51). Even the largest and most vigorous survivors of the struggle have live crowns that are too short and too narrow in proportion to the total height of the tree.

The silviculturist, while recognizing the value of the struggle for existence in assisting the production of lumber free from knots, attempts, by making thinnings, to avoid the disadvantages of ex-

D = Dominant trees. C-D = Codominant trees. I = Intermediate trees. O = Overtopped trees.

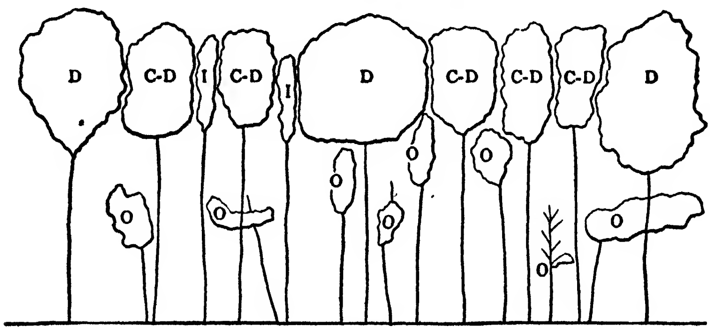

FIG. 50.

The relative position of trees of the different crown classes.

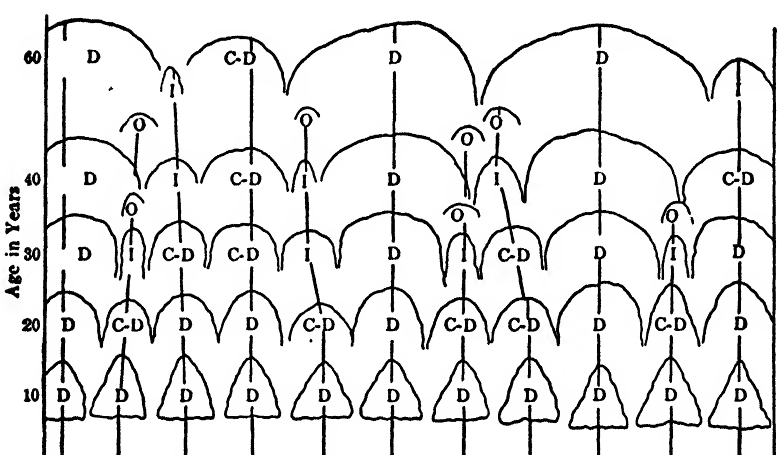

FIG. 51.

The passing of trees from the dominant down to the overtopped crown class with advancing age, as a result of the struggle for existence. The letters indicate the crown classes of the trees.

cessive competition and the inclusion of undesirable species and trees of poor form in the final stand. He endeavors to keep the more promising trees growing steadily by removing neighboring trees before their competition becomes injurious.

Classification into Crown Classes. The outward sign of the struggle for existence is found in the relative position and condition of the tree crowns. The selection of the trees to be favored and of those to be cut in thinnings is based largely upon (*a*) relative position and condition of the crown together with (*b*) the character and condition of the bole and (*c*) the health of the tree. This statement applies more accurately to pure stands than to mixed stands where choice between species affects the selection. In general, in comparing individuals of the same age, a tree's health is correlated with its relative position in the crown canopy, the largest and best-developed crowns being those of the most vigorous individuals; yet many injurious agencies such as plant and insect pests affect the health of trees independently of their position in the crown canopy. Character and condition of bole, while closely correlated with the relative position of the tree in the crown canopy, is also influenced by such factors as density of the stand and by injuries to the bole from insects, diseases, fire, and other causes. Hence a crown classification to be most useful in thinning practice should cover points (*a*), (*b*), and (*c*).

The crown classification most widely used in American thinning practice is the one favored by the Society of American Foresters and is as follows:

Dominant: Trees with crowns extending above the general level of the crown cover and receiving full light from above and partly from the side; larger than the average trees in the stand, and with crowns well developed but possibly somewhat crowded on the sides.

Codominant: Trees with crowns forming the general level of the crown cover and receiving full light from above but comparatively little from the sides; usually with medium-sized crowns more or less crowded on the sides.

Intermediate: Trees shorter than those in the two preceding classes but with crowns extending into the crown cover formed by codominant and dominant trees; receiving a little direct light from above but none from the sides; usually with small crowns considerably crowded on the sides.

Overtopped: Trees with crowns entirely below the general level of the crown cover, receiving no direct light either from above or from the sides. *Synonym:* "suppressed."

This crown classification is simple, easily learned and readily applied in the forest and will fill the ordinary requirements of thinning practice. The principal criticism which has been advanced is that this classification considers only the relative position and

condition of the tree crowns and overlooks condition of bole and health of the tree. This objection is more fancied than real, because of the correlation already mentioned between relative crown position and both character of bole and health of tree. In practice, in making selection of trees consideration should always be given to injuries affecting the condition of the bole and health of the tree, even though subdivisions in the classification are not specifically set up for this purpose.

However, to remedy this alleged defect and to provide further subdivisions under the principal crown classes for use not only in practice but particularly in thinning research several more elaborate crown classifications have been developed. One classification of this type which has been widely employed in Europe and has served as the model for other classifications suited to the needs of various individual countries, was perfected by the Association of German Forest Experiment Stations in 1902 (Gutmann 1925).

A classification suggested by Schädelin (1931) utilizes the decimal system in classifying the trees; it presents a classification less elaborate than those previously issued and is recommended by him as being detailed enough to answer the needs of experimental work as well as being simple enough for use in practice. Briefly Schädelin's arrangement is as follows:

The trees in the stand are classified into the customary four crown classes — dominant, codominant, intermediate, and overtopped — which are given respectively the following numbers: 100, 200, 300, 400. Each tree is also graded on its stem quality as good, average, or poor, and designated respectively as 10, 20, or 30. Finally each tree is graded according to the quality of its crown as good, average, or poor and given the number respectively of 1, 2, or 3. Each tree then may be identified by a three-place number.

Table IX is translated from Schädelin (1931). Here are given all the combinations which it is possible to find in the stand in respect to tree class, stem quality, and crown quality.

TABLE IX

Quality of stem	*Tree class*											
	Dominant			Codominant			Intermediate			Overtopped		
	Quality of crown			*Quality of crown*			*Quality of crown*			*Quality of crown*		
	Good	Average	Poor	Good	Average	Poor	Good	Average	Poor	Good	Average	Poor
Good	111	112	113	211	212	213	311	312	313	411	412	413
Average	121	122	123	221	222	223	321	322	323	421	422	423
Poor	131	132	133	231	232	233	331	332	333	431	432	433

The British Forestry Commission (MacDonald 1931) adopted Schädelin's decimal system in slightly modified form. They added two additional tree classes, namely, dead or dying trees and diseased trees, giving them the numbers 500 and 600 respectively.

Gevorkiantz, Rudolf, and Zehngraff (1943) have published a relatively elaborate tree classification for aspen, jack pine, and second-growth red pine, based primarily on Scandinavian classifications. A summary of this new classification is reproduced in Table X.

The term " vigor classes " is sometimes used in classifying the relative capacity of individual trees for growth. Of course crown development as classified in crown classes indicates this capacity for growth, but the health (pathological condition) of two trees of the same crown class may differ. The best visible expression of such variation in pathological condition will be found in the color of the foliage and in its abundance. Whether it is worth while making a vigor-class division inside of, independent of, or in the place of the usual crown-class division is a problem that may merit consideration in dealing with any specific forest type. It is possible to take cognizance of relative vigor as the trees within a crown class are being selected for removal without having special vigor-class subdivisions.

From attempts over a period of years to apply elaborate classifications both in practice and in experimental work, the author has reached the conclusion that the simple crown classification given on page 217, with the added point of recognizing diseased trees as a special class, should be adequate for the ordinary requirements in thinning practice and experimentation.

As earlier indicated, thinnings are employed in evenaged stands, or in the individual evenaged groups (small or large) which make up so great a part of irregular and unevenaged stands. Thinnings are employed only in such evenaged stands or groups, in other words only when production is of the evenaged type. Hence it follows logically that the systems of crown classification, which have been developed for use in thinning practice and experimentation, are intended for evenaged stands, and also are adequate to control marking for thinning operations.

This point is emphasized here for the reason that some confusion exists, because tree or crown classifications drawn up for other purposes than use in thinning practice have been incorrectly taken as applying to such practice. For an illustration of this point the reader is referred to the tree classification for the selection forests of the Sierra Nevada prepared by Dunning (1928) which is presented on page 298. Dunning's classification is intended for unevenaged

TABLE X

SUMMARY OF TREE CLASSIFICATION FOR ASPEN, JACK PINE, AND SECOND-GROWTH RED PINE IN THE LAKE STATES BY GEVORKIANTZ, RUDOLF, AND ZEHNGRAFF (1943)

Position and Relation to Surrounding Trees	*Progressive* 1. Head dominants. Dominating surrounding trees with crowns definitely above the general level of the canopy. 2. Strong dominants. In competition with trees of the same crown class but of poorer development. *Provisional* 3. Conditional dominants and codominants. Competing with trees of the same crown class and development and not in immediate danger of being crowded out. *Regressive* 4. Weak dominants and codominants. Competing with trees of better development. 5. Intermediates. Competing with trees of higher crown class and development, occupying small holes in the canopy. 6. Suppressed. Trees definitely below the general level of the canopy. 0. Open-grown. Isolated trees.
Crown Density	*a*. Good crown. At least ⅔ filled, with foliage of healthy green color and normal size. *b*. Medium crown. *c*. Poor crown. Less than ⅓ filled or with foliage of poor color and of less than normal size.
Soundness	1. Sound. 2. Diseased. With visible signs of fungus or insect damage. 3. Badly scarred or damaged. Fire scars, visible rot at base, dead top, etc. 4. Defective or cull. 5. Dying or dead.
Form	*a*. Good form. Straight boles and uniform, well-developed crowns. *b*. Forked. Only when merchantability is affected. *c*. Limby. Excessive limbiness affecting merchantability. *d*. Crooked or bent. Too much lean or sweep. *e*. "Whippers." Trees with small, narrow crowns whipping or injuring the crowns of neighboring trees.
Utility	S. Sawlog trees. (Subject to modification under different market conditions.) S^1 Usable for piling. S^2 Usable for mine timbers. S^3 Usable for lumber. S^4 Usable for box lumber and lagging. P. Cordwood trees. P^1 Usable for pulpwood. P^2 Usable for poles, etc. F. Fuelwood trees.

virgin forests and was drawn up for the purpose of assisting in marking practice on timber-sale areas where the cuttings must be classed primarily as reproduction cuttings. So far as known, thinnings are not made in the selection forests of the Sierra Nevada because of economic reasons. For the purpose for which it was made this classification is excellent. It has been of value in improving and systematizing marking practice and has proved to be applicable for this purpose beyond the boundaries of the Sierra Nevada.

The subject of tree classifications is taken up in further detail in the chapter entitled " Methods of Controlling Cuttings."

Time to Start Thinnings. Theoretically thinnings are needed just as soon as the struggle for existence between the trees in a stand threatens to become injurious. This condition may arise within the first year after establishment in a densely stocked stand in tropical climates and, except in wide-spaced plantations and open natural stands, is rarely deferred later than the tenth to fifteenth year. The density of stocking, the productive power of the site, the type of product to be grown, the spreading habit and tolerance of the species, and the cost determine the time for making the first thinning. In stands where neither cleanings nor improvement cuttings have been required, the first thinning is likely to be needed earlier than in stands that have received either of these other kinds of cuttings.

Today the question of expense is of great importance in determining in practice the time of the first thinning. In young stands the material removed may not be valuable enough to pay the cost of the operation.

Where funds for cultural operations are not available, it is impossible to make thinnings as early in the life of the stand as the best interests of the crop demand. Over a large part of the forest area the first thinning has to be postponed until the value of the product removed will at least pay the expense of the operation. In temperate climates this point frequently is not reached until after the thirtieth year. This situation is not ideal, and it may result in reducing the crop production from all areas affected.

Where forest properties are already on a sustained-yield basis with an annual revenue available, the first thinnings should be made just as soon as they are needed and be paid for out of current revenue. On forest properties not yet furnishing an adequate annual income, early thinnings should be made only to the extent that funds for such silvicultural investment can be obtained and the returns appear to justify the investment.

A favorable fact is that, with most species and stands, delaying the

first thinning for some years beyond the best time does not result in failure to secure an acceptable crop. Undoubtedly the development of the crop will be affected, but how much loss will be incurred by delaying the first thinning is a point not yet adequately investigated.

There always exists the danger that the trees in densely stocked stands may compete so fiercely with one another that all the individuals will be seriously affected (suffering abnormal reduction of live-crown and root system), and as a result the growth of the stand will stagnate. This may happen with almost any species where density of stocking is exceptionally high but is more apt to occur where moisture is deficient and particularly with certain species inherently of low ability in expressing dominance. By expression of dominance is meant the division of the trees in an evenaged stand into size classes, and consequently into crown classes, because of unequal growth rates. A wide range of size classes in such a stand is an indication of good expression of dominance with little danger of growth stagnation. Eastern white pine is a species which inherently has the ability to express dominance (Deen 1933).

The silviculturist should always be on the watch for young stands that may be in danger of stagnation and in these stands should make the first thinning as soon as needed even though an expense is involved.

An interesting example of a species susceptible to stagnation of growth is described by Craib (1933). He recommends for the black wattle as grown on a 16-year rotation for tanbark in South Africa, in order to avoid stagnation of growth, a first thinning when the plants are between 1 and 2 months old and 3 to 8 inches in height, a second thinning when between 2 and 6 months old, and 3 other thinnings within the next 2½ years. When 3 years old the black wattle stand per acre has been reduced from 40,000 or more seedlings, 3 inches tall, to 200 stems 38 feet in height. The black-wattle-tanbark industry, being already on an annual income basis and profiting greatly from the ultimate effect of the thinnings, is in a position to pay the costs of the first thinning and such subsequent thinnings as fail to pay immediate expenses.

Stagnation of growth is so real a danger with black wattle that Craib recommends thinning early and frequently enough so that only dominant trees are present in the stand. The thinnings should be made often enough so that live crown is maintained at nearly 100 per cent of the total height in youth, 50 per cent in middle age, and 35 per cent at maturity. Maturity apparently is set at 16

years. This example illustrates the initiation of thinnings before competition begins. The work of O'Connor (1935) and Craib (1933 and 1939) has called attention to the desirability of thinning schedules, which would make thinnings before the growth of trees in a stand has been slackened by any competition with one another rather than waiting until after competition has begun. The idea has greatest value, in regard both to possibilities of application and to results to be secured under climatic and economic conditions characteristic of South Africa where these men carried on their investigations. The factors favorable to the plan include thousands of acres of regular, pure plantations of relatively light-demanding conifers, such fast growth rate that in terms of possible stagnation months are as important as years are elsewhere, excessive costs of artificial establishment often involving expensive cultivation, and good markets for products of desired sizes (see also page 225).

It is possible for a stand in need of a thinning to remain so long unthinned that it fails to respond when finally such a cutting is made. In a situation of this kind the competition has continued so long and fiercely, and the struggle between the individuals has been so even, that diameter and height growth have suffered, and the crowns, even of the dominant trees, have been reduced to small tufts at the tops of weak, slender stems. If a thinning is made in such a stand, the trees left are likely to suffer from drought, sunscald, and insect attacks or to be thrown or broken by wind. Such trees have lost the ability to respond immediately, if at all, with increased growth. Stands densely stocked and growing on poor soil are the ones most likely to be in this condition. The appearance of the crowns and boles, particularly the length of crown in relation to the total height of the tree, is the best indication of whether a stand has gone unthinned so long as to be incapable of profiting by a thinning (see also page 226).

Methods of Making Thinnings. From what has been said previously, it will be evident that the relative position of the crowns of the trees is of primary importance in determining which trees should be removed and which left. This is true except in very young stands in which little or no differentiation into crown classes has as yet taken place, and many more trees than can safely be allowed to remain are equal in development. Here spacing may be influential in determining selection.

The thinning should provide opportunity for expansion of the crowns and root systems of the remaining trees yet should not so reduce the crown cover as to render the area understocked. Crown

classes furnish the principal basis for cutting or leaving a tree, and the relative position of the crown of each tree must be observed with respect to its associates. The distribution of the trunks of the trees over the area is not so important because it may not be indicative of the position of the crowns. If thinnings are started early in the life of the stand and repeated regularly, the stem distribution over the area is likely to become uniform.

The highest production as a result of thinnings can be secured only by leaving the largest number of trees per acre consistent with thrifty development and profitable growth of the individual. In this connection, it should be remembered that volume growth of the individual tree depends not only on growth in the two dimensions — height and diameter at breast height — but also upon changes in form of bole due to diameter growth at other points than at the classification point (breast-high). Excessively fast diameter growth at breast height, secured by very heavy thinnings, is not likely to be accompanied by similarly fast diameter growth higher up the stem. Thus the tree becomes less full-boled.

The individual tree because of its abundant foliage may grow in volume fastest out in the open, entirely isolated. This arrangement results in a low production per acre because the area is only partially stocked. The ideal is to find and maintain the right density of stocking to give the highest production per acre. As brought out by Möller (1931) the best thinning physiologically will be one that produces the largest foliage volume, divided in the best manner on the most desirable trees, while at the same time the soil is lighted to the proper degree. In the last analysis production per acre should involve not quantity alone but also value of product. The determination of the ideal combination of different species, on a variety of sites, at different ages, and when grown for different products offers a wide field for investigation. Today the determination of the right density of stocking is based largely on guesswork rather than scientific methods.

When quantity production alone is considered, the ideal density of stocking at any given age may be expressed as that combination of trees which, for the given conditions, is the minimum number per acre able to utilize completely the available supplies of moisture and nourishing materials. Where considerations other than quantity production are involved, this conception of the ideal density of stocking may require modification.

The theory is sometimes advanced that a heavy early thinning should be made, reducing the trees per acre to such a number as

would, toward the end of the rotation, completely utilize the available supplies of moisture and nourishing materials. Under this plan the area would evidently be only partially stocked until near the end of the rotation and the trees at first would grow in isolated position. The final yield in quantity is claimed to be greater under this plan than in stands of closely grown trees, but the boles are likely to be less cylindrical and the wood to be more knotty and with wider growth rings. Whether the yield even in quantity would be greater is questionable, when the material secured in thinning the closely grown stand is added to the final yield, and when possible soil deterioration and the probable competition of lesser vegetation on the open areas between the wide-spaced trees are considered.

There may be situations where the quality of the crop would be improved by a heavy early thinning. Craib (1939) furnishes as an illustration plantations of yellow pines in South Africa. He advises, on second- and third-quality sites, but not on the best sites, thinning so radical at an early age that extra diameter growth is induced, making it possible to secure trees of much larger dimensions than those secured under past methods on second- and third-quality sites. He shows that volume production is reduced by these heavy thinnings, but value production is increased enormously because timber of large diameter is worth much more than the very small material secured in the past. When quality depends on size, irrespective of the rate of diameter growth and specific gravity of the wood, heavy early thinnings will be more attractive than when quality is determined primarily by the technical properties of the wood.

As an expression of the ideal density of stocking, the basal (sectional) area at breast height, the number of trees, or the volume per acre are often taken. All or any one of these three may be used, but the first is considered the most desirable, because it is more easily calculated in the field than the volume and is not subject to such large variations as the number of trees. With increase in the age of the stand, the number of trees per acre must decrease appreciably because the crown space required by each tree is steadily enlarging; but basal area for a given grade of thinning should in the systematically thinned stand remain relatively constant or show only gradual change. The volume per acre of course rises from period to period, even though the basal area is reduced to a constant amount at the time of each thinning. For example, in an experiment with eastern white pine, in a moderately heavy low thinning, the basal area has been brought after each of the last four thinnings to approximately 100 square feet per acre. Whether under the conditions of

the experiment the density of stocking represented by this figure is the best and whether a constant rather than a gradually increasing or decreasing amount of basal area per acre should be maintained are questions requiring further experimentation. European experience indicates that after middle age the basal area may well be kept for the rest of the rotation at approximately the same figure, the periodic growth in basal area being removed at each thinning.

Another measure of the proper density of stocking is the ratio of the length of the live crown to the total height. This is known as the live-crown ratio. It has the advantage of being easily ascertained in the field. The live-crown ratio is determined by the competition between adjoining trees in their struggle for existence. Since thinnings relieve the reserved trees from competition to any desired degree, they can control the live-crown ratio. The correct percentage of total height which live crown should occupy will vary, depending chiefly upon species, age of stand, and objectives and methods of management. If one general figure is wanted, it may be set for middle-aged and mature stands at 30 to 40 per cent of the total height. The principal product which is being grown has an important influence in determining the best live-crown ratio to maintain. If trees stocky at the butt and tapering fairly fast are wanted, a high live-crown ratio should be kept, whereas if slow-grown timber with little taper in the stem is needed, a low live-crown ratio is demanded.

Live-crown ratio should be highest in young stands and then decrease with advancing age. As an indicator of the need for thinning, particularly in young stands which have not previously been thinned, live-crown ratio is of great value and should be ascertained frequently to fix the time for making the first thinning. As long as a satisfactory live-crown ratio is maintained, a stand need not be thinned, no matter how dense it appears, until the thinning will pay an immediate profit over expenses. If the live-crown ratio is evidently dropping to a dangerously low point, a first thinning may be required at a present financial loss as an investment for the future.

All methods of thinning should have as their goal the maintenance of the proper density of stocking.

Four distinct ideas in the method of making thinnings can be recognized, each involving a different principle in the selection of the trees to be removed. Relative crown development of the individual trees is the primary basis for selection under each of the first three methods. In the fourth, spacing of the stems is the

first consideration, although even here crown development cannot be entirely neglected. The four methods may be termed:

1. The low thinning method.
2. The crown thinning method.
3. The selection thinning method.
4. Mechanical thinning.

To illustrate the different principles in selection of trees for thinning a series of diagrams are presented, Figures 52 to 66 inclusive. Figures 57, 58, 59, and 66 show the outlines of tree crowns as viewed from the air directly above the stand. The remainder of the figures give profiles on a vertical plane through the stand. The original vertical plane (Fig. 52) upon which the other diagrams are based was designed from data secured in an unthinned stand of mixed hardwoods in southern Connecticut, about 50 years of age, with the best dominant trees approximately 55 feet in height. In order to furnish several examples of each of the different crown classes and to bring out better the wide differences in form characteristic of these crown classes, conditions of dense stocking have been portrayed in the diagram. Most of the thinning to be done in this country for the next decade will be in stands never previously thinned. Hence such diagrams will be more useful. Furthermore the greatest variations in form between crown classes can be observed in such stands. The relations portrayed, as regards live-crown ratio and actual width, length, and form of crown, are all possible from the growth habits of the various species in the mixture. However, it was not intended to make the diagrams to actual scale for any particular species. Such a diagram would have meaning only for one species, age class, site, density of stocking, and, in managed stands, method of treatment. These diagrams are for general use in contrasting crown-class relationships and in studying the differences in application of the thinning methods.

Each thinning method will now be discussed in turn.

The Low Thinning Method (sometimes termed "thinning from below," or the "ordinary" or "German" method). In this method the principle is to take out the poorest crown class (overtopped trees) first, and then to work upward in consecutive order through the better crown classes, increasing the number of classes removed with the severity of the thinning. The weakest trees and those which must be utilized immediately to save them from death and decay are cut with as many more of the intermediate, codominant, and dominant trees as the desired severity of the thinning warrants. All trees of

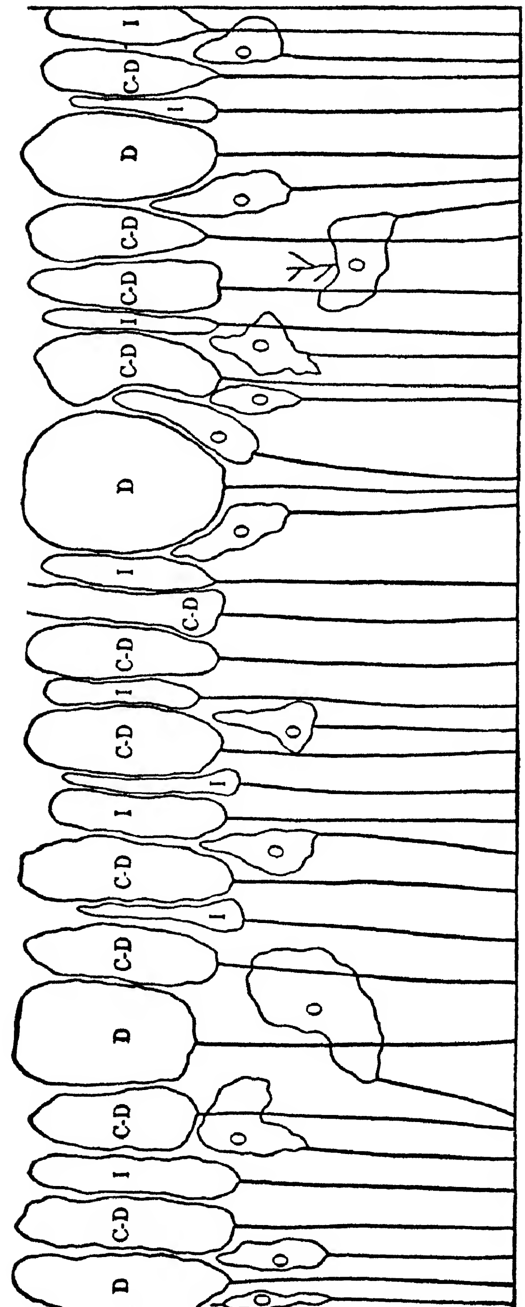

FIG. 52.

A 50-year-old evenaged stand of hardwoods before thinning. See Figures 53, 54, 55, and 56 for the same stand after low thinnings of various grades of severity. The letters indicate the crown classes of the trees.

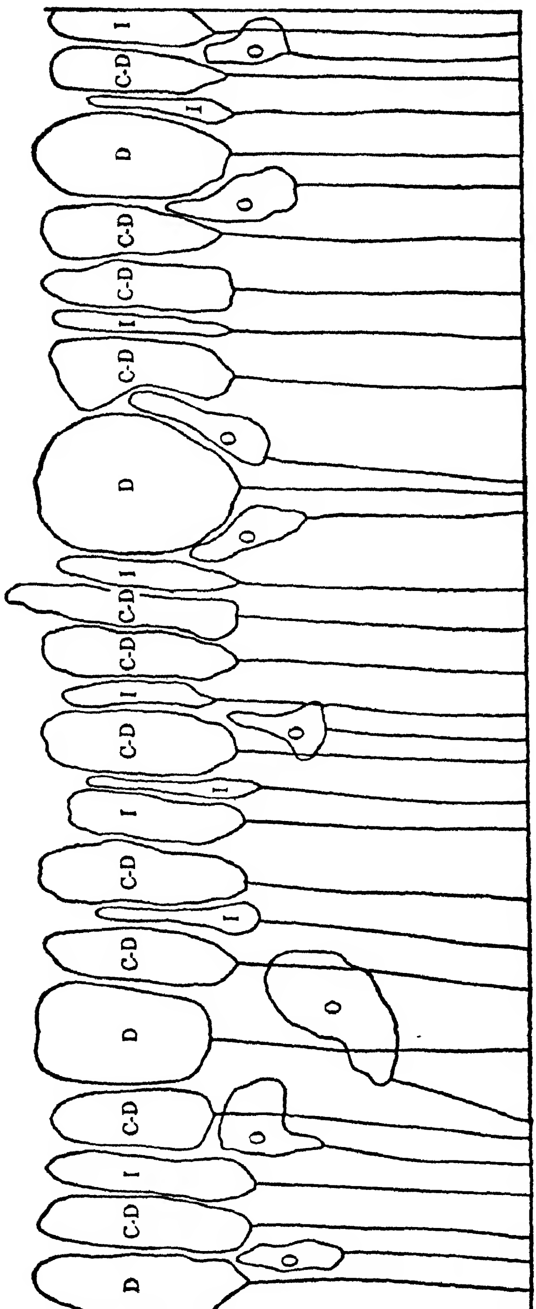

FIG. 53.

Same stand as in Figure 52. An *A*-grade thinning has been made removing poorest overtopped trees. Note that the forest canopy has not been broken.

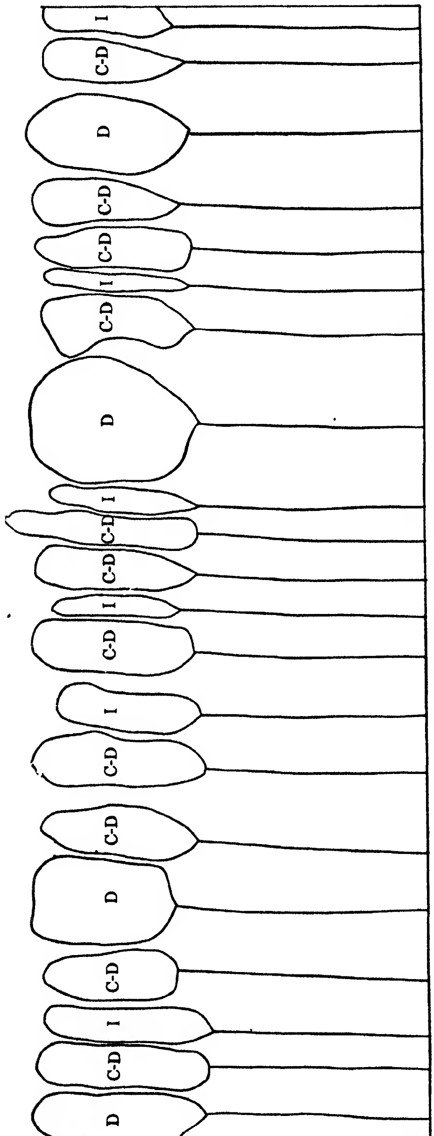

Fig. 54.

Same stand as in Figure 52. A *B*-grade thinning has been made removing overtopped trees and the poorest intermediate trees. The forest canopy is still practically unbroken.

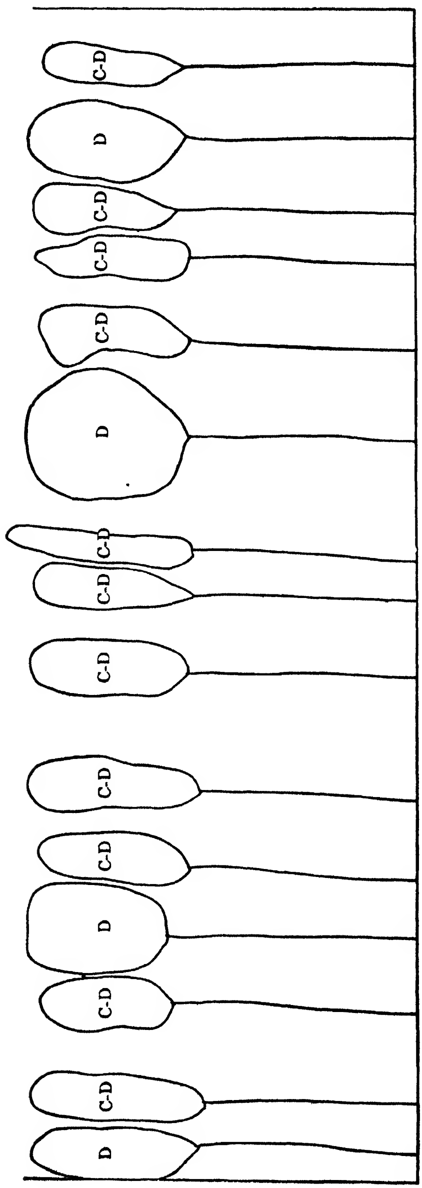

Fig. 55.

Same stand as in Figure 52. A *C*-grade thinning has been made removing overtopped and intermediate trees. This is a conservative *C*-grade thinning.

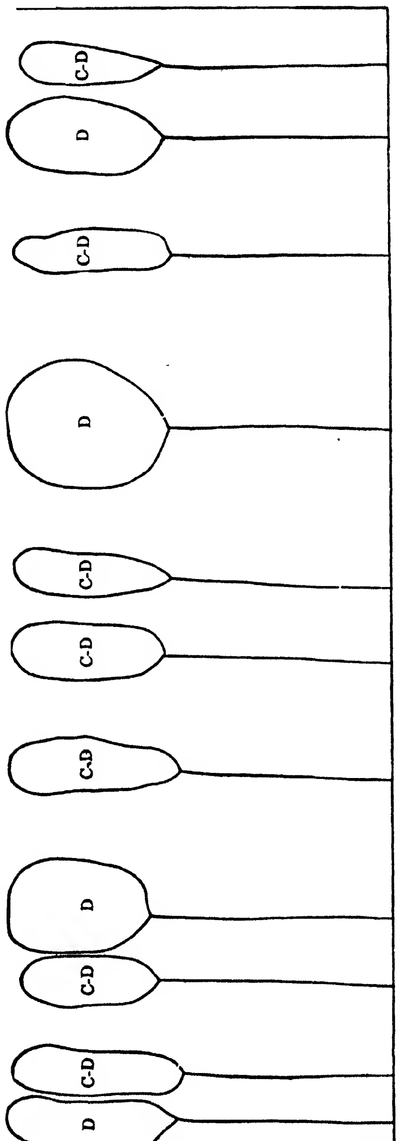

FIG. 56.

Same stand as in Figure 52. A *D*-grade thinning has been made removing overtopped, intermediate, and some codominant trees.

a crown class are cut before trees from a higher crown class are taken, except that overtopped trees are usually left if unmerchantable. After the heaviest thinning some members of the dominant class will remain but none of the other classes. Less severe thinnings leave representatives of other crown classes.

Several grades of severity in low thinnings are recognized. There is some variation in practice as to the exact severity of each grade.

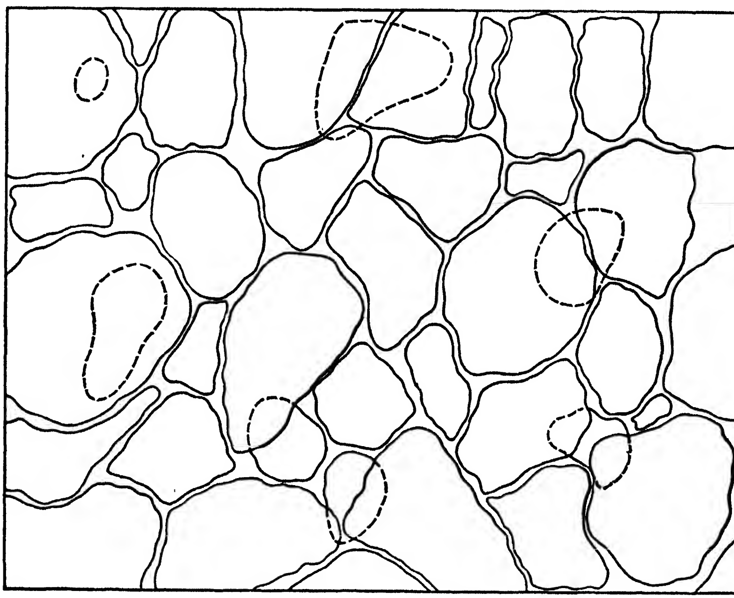

FIG. 57.

Diagram showing the arrangement of crowns in a 50-year-old hardwood stand in need of a thinning. The crowns of overtopped trees are indicated by broken lines. Compare with Figures 58 and 59.

Table XI shows a conservative and a radical application of the different grades as recognized in the literature. It should be understood that these thinning grades originally were used in Europe at a time when the tendency was to take out very small quantities of material in thinning, and both *A* and *B* grades were often employed. Today most foresters consider a *B*-grade thinning light, *C* moderate, and *D* heavy.

Another point to be considered in appraising thinning grades is that the habit of the species has influence in determining the severity of a thinning. A low thinning in a stand of a light-demanding species, taking out trees of a given crown class, will be a lighter-grade

TABLE XI

Grade	Trees Removed in a Conservative Application of the Low Thinning Principle	Trees Removed in a Radical Application of the Low Thinning Principle
A. Light	Poorest overtopped	Overtopped
B. Moderate	In addition, remaining overtopped and poorest intermediate	In addition, intermediate
C. Heavy	In addition, remaining intermediate	In addition, a few codominant
D. Very heavy	In addition, many codominant	In addition, most of the remaining codominant

thinning than the removal of the same crown class in a stand of shade-enduring species. The reason is that in stands of shade-enduring species there is likely to be an assortment of low-class trees,

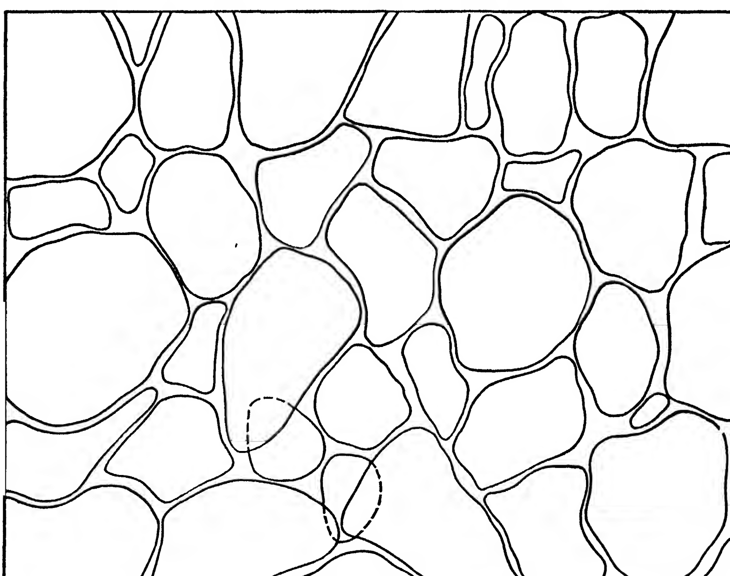

FIG. 58.

The same stand as shown in Figure 57, but after an *A*-grade thinning removing overtopped trees has been made. Note that the main crown canopy has not been opened by this light thinning. Compare with Figure 59.

living on for many years, and furnishing material for a *B*- or possibly even an *A*-grade thinning. On the other hand, in stands of light-demanding species the lower-class trees die quickly and do not furnish adequate material for the lower grades of thinning. For such species

a C-grade thinning may be the lightest that can be undertaken. This, however, is not a good reason for calling C grade a light thinning. Figures 52 to 59 illustrate the low thinning principle.

The amount removed in thinnings as applied in this country varies from below 5 per cent of the total cubic volume, in a grade-A thinning

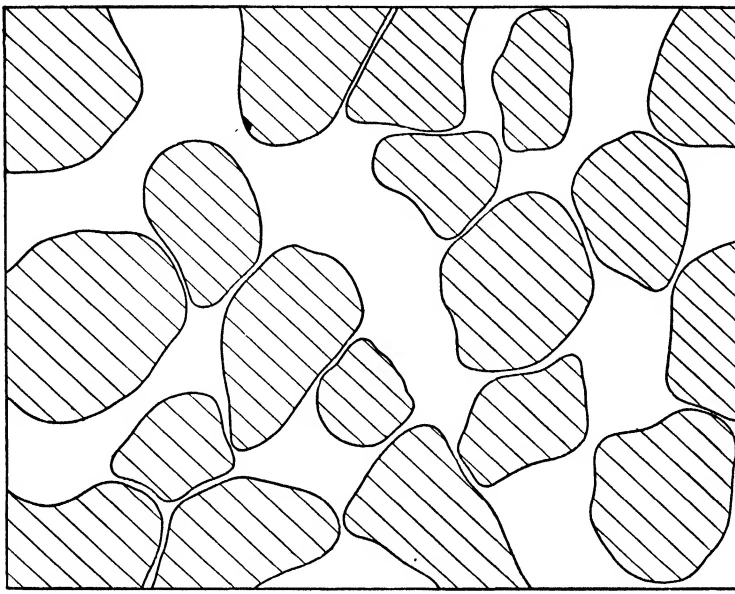

FIG. 59.

The same stand as shown in Figure 57, but immediately after a D-grade thinning, removing overtopped, intermediate, and many codominant trees. Note that the crown canopy has been opened and every one of the remaining trees given increased room on one or more sides. Compare with Figures 58 and 66.

(rarely used), to over 40 per cent, in a grade-D thinning. Experience in this country is based upon the first thinning at different ages in stands previously unmanaged.

The author has found that in second-growth hardwood stands in Connecticut, 40 to 50 years of age, a grade-C thinning in a stand previously unthinned, on good soil, will remove approximately one third of the cubic-foot volume, and a second thinning 10 years after the first will take out 20 to 25 per cent.

In middle-aged stands of eastern white pine heavy thinnings, repeated at intervals of 5 to 8 years, may be expected to yield approximately 20 per cent of the total volume before cutting, and light thinnings about 12 to 15 per cent.

As an indication of what may be obtained when stands are repeatedly thinned, Table XII, showing the percentage of the total cubic-foot volume removed in thinnings at different ages has been prepared from yield tables given by Schlich (1925) and secured by him from the original tables compiled by Lorey for silver fir, Wimmenauer for oak, and Schwappach for beech.

TABLE XII

PERCENTAGE OF TOTAL CUBIC-FOOT VOLUME AT DIFFERENT AGES REMOVED IN THINNINGS IN STANDS OF AVERAGE QUALITY

Age	*Silver fir, Lorey's yield table*	*Oak, Wimmenauer's yield table*	*Beech, Schwappach's yield table*
40	—	5%	—
50	7%	7	4%
60	9	8	9
70	9	7	8
80	10	7	8
90	10	6	8
100	8	6	9
110	8	5	10
120	6	5	9
130	4	5	8
140	2	4	7
	30%*	30%*	40%*

* Percentage of total yield during the 140-year rotation.

Another example of results to be expected under systematic application of thinning is shown in Table XIII. These data have been taken from Von Wülfing's yield tables for teak plantations in Java (Champion 1934, pp. 28-29) and represent his best site. Approximately 65 per cent of the total yield is taken out in the thinnings. It is of interest to note that the total basal area of the main crop increased only 26 per cent during the last 50 years of the rotation, while the total volume in the main crop increased 44 per cent.

The results of the four grades of low thinning differ. In general the *A* grade gives somewhat lower total production than the *B* and *C* grades. This is logical since an *A*-grade thinning does little to lessen the struggle for existence among the trees in the stand. In some instances the *D* grade may go to the other extreme and open the stand so much that here again the volume growth is less than in the *B* and *C* grades. On the whole the *B* and *C* grades (Gutmann 1925) are likely to give the best height growth and volume production per acre, although there is good evidence for asserting that growth

is the same in the different grades of thinning, provided the stand is not kept so thick as to prevent development of good crowns or so open as to be understocked. The truth of the matter is that it is extremely difficult to get good comparative results, particularly results that can be applied outside the immediate locality where they are secured. In the last analysis the best density of stocking and consequently the proper degree of thinning are local matters and therefore subject to variation.

TABLE XIII

YIELD OF TEAK PLANTATIONS IN JAVA ON SITE QUALITY VI (BEST SITE)*

	Main crop				
Age, yr.	*Average height, ft.*	*Total basal area, sq. ft.*	*Number of trees*	*Accumulated yield of thinning, cu. ft.*	*Total yield, cu. ft.*
10	69	62	202	0	1,730
20	92	79	122	2,445	5,210
30	107	90	81	4,685	8,255
40	118	100	59	6,720	11,135
50	127	108	48	8,485	13,650
60	134	116	41	10,025	15,870
70	141	123	35	11,395	17,875
80	148	129	31	12,630	19,675
90	153	135	28	13,745	21,285
100	158	141	26	14,750	22,735
110	162	146	24	15,655	24,050
				65% of total yield	

* Data taken from page 28–29 (Silviculture Series) *Forest Bul.* 87, Forest Research Institute. Dehra Dun. 1934.

Even if the different grades of thinning do not differ appreciably in the total production, they allow a wide range as to the number of individuals upon which the growth is distributed, and upon the percentage of the total production removed in the thinnings. These points will exert an important influence upon the financial outcome. Diameter growth is stimulated by the heavier grades of thinning. Hiley (1930) indicates that very heavy thinnings (*D* grade) are financially the best and that the *C* is better than the *B* grade. Another effect of heavy thinnings may be a change in form of bole, the trees becoming less full-boled.

Accretion cuttings (termed also "increment cuttings" or "*E*-grade thinnings"). Accretion cuttings are thinnings heavier than the *D* grade which remove all the trees in the codominant and lower crown

classes and often some individuals in the dominant class. The trees remaining are free on all sides. The purpose of accretion cuttings is to obtain exceptionally rapid diameter growth on individual trees, not attainable even with a D-grade thinning. They are started usually when the stand is between 30 and 70 years of age. An accretion cutting removes from 20 to 50 per cent of the basal area remaining in stands previously thinned.

An accretion cutting, except with light-demanding species especially suited to heavy cuttings, may reduce the density of stocking to such an extent that the volume production per acre is lowered. The increased value of the large trees grown as a consequence of the accretion cutting may offset financially any such reduction in total yield. This is not a foregone conclusion but depends on the species, site, and relative value of large-sized material.

Such a radical opening of the canopy encourages the establishment of reproduction. If for any reason natural regeneration does not follow the accretion cutting, an understory may be established by artificial means to prevent the development of an undesirable growth of grass, weeds, or woody shrubs.

Accretion cuttings, since their purpose is to obtain exceptionally fast growth and large dimensions on selected trees, will show the most striking results on soils where food materials and moisture are available in abundance. On the other hand, they may be most needed on poor sites, where only by a drastic reduction in number of trees per acre can enough nutrient materials be made available for selected trees to bring them up to profitable sizes within a reasonable rotation length.

In applying the shelterwood method there often exists an excellent opportunity for accretion cuttings. Here it amounts simply to an early starting of the reproduction cuttings. The more promising trees of the old crop are isolated for a long period of rapid growth. The new crop of seedlings becomes established beneath the old trees, forming an understory, until set free by the final cutting. In Chapter VI, page 121, it was stated that thinnings frequently resulted in starting reproduction. Accretion cuttings, the heaviest grade of thinning, resemble reproduction cuttings of the shelterwood type.

The Crown Thinning Method. Variously called the "French method" (because of its origin and early use in France), "éclaircie par le haut" (thinnings from above), "high thinning," "Danish thinning," or "thinning in the dominant." The principle of the crown thinning method is to cut in the upper crown classes in order to favor development of the most promising trees of these classes, meanwhile

cutting in the lower crown classes only trees that will not live until the next thinning. Both in the low thinning and crown thinning methods a portion of the codominant and dominant stand is developed by the repeated thinnings to form the final yield. In this respect the two are in contrast to the selection thinning method.

The crown thinning differs basically from the low thinning in two respects: first, in that no matter how lightly applied, the principal cutting is in the codominant or dominant classes, and second, in that the bulk of the intermediate class and the healthier portion of the overtopped class remain after each thinning. The consequence of this procedure is that the best trees are afforded opportunity for continuous rapid growth while at the same time the stand is kept closed and the soil protected by the constant presence of the intermediate and overtopped stories.

Great flexibility, permitting the favoring and developing of fine individual trees, is characteristic of the crown thinning method. The protection afforded the soil by the trees of the subordinate crown classes permits openings to be made safely in the upper crown canopy, thus affording the silviculturist wide latitude in stimulating the growth of selected trees.

A crown thinning frequently involves the removal of dominant trees and the leaving of openings in the main canopy which do not close for several years. Undue exposure of the site as a result of the heavy thinning is prevented because of the cover afforded by the intermediate and overtopped trees left standing. From among the overtopped trees the poorest are removed to secure utilization before they become worthless, unless they are needed to fill an opening made by the cutting (see Figs. 60, 61). Any badly bent or broken trees or other trees not likely to live until the next thinning are also cut.

The advantages of the crown over the low thinning method are that:

1. Bigger timber can be produced in the same time or timber of a required size in a shorter time, owing to the freedom for expansion afforded the crowns of the selected trees. As individuals they have more room than in the low thinning method because the intermediate and overtopped trees preserve a close cover and obviate the necessity of the dominant stand's maintaining a complete canopy.

This understory of lower-class trees, by its shading effects on the stems, may be of assistance in preventing the development of epicormic branches on the stems of dominant trees. For further discussion of epicormic branches see page 195.

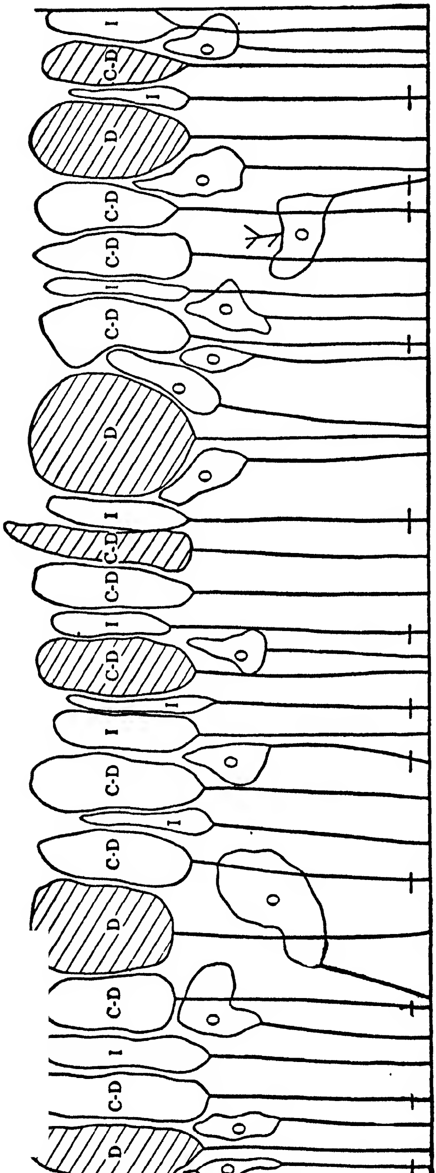

Fig. 60.

A 50-year-old evenaged stand of hardwoods marked for a crown thinning. Trees to be removed are indicated by dashes. The trees which have been freed in the thinning are designated by cross-hatching. Compare with Figures 52, 53, 54, 55, 56, and 62.

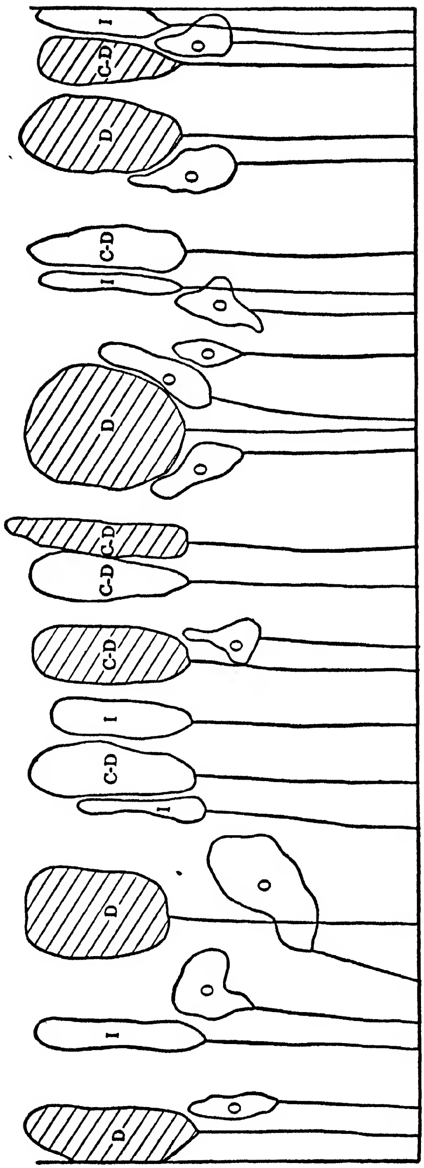

FIG. 61.

The same stand as in Figure 60 after the crown thinning has been made. Trees of any crown class which were interfering with the best crop trees have been removed. Otherwise nothing was cut except three overtopped trees which would have died before the time for a second thinning. The trees which have been freed in the thinning are designated by cross-hatching. Note that they now have room for development. Compare with Figures 53, 54, 55, 56, and 63.

2. It gives higher immediate cash returns from the thinnings, because the material removed is larger and better on the average, as comparison of the crown classes removed in each of the two plainly indicates.

3. Any part of the area not occupied by the main stand is utilized by the understory trees which are able to continue growth, slowly producing cordwood as the principal product. (Under the low thinning method the heavier thinnings tend to stimulate a growth of grass, weeds, and shrubs.) The understory serves also to prevent the establishment of reproduction at a time when it is not wanted.

Comparisons between crown thinnings and low thinnings indicate no significant difference in total production per acre. Since crown thinnings are considered better for improving soil conditions (Burger 1927) it would seem that over long periods of time a somewhat higher production should result than when low thinnings are applied.

The principal disadvantage of crown thinnings, but not always a serious drawback, is the fact that the understory trees left standing are a hindrance in the work of cutting and transporting the material from the area.

Crown thinnings should be light, if started before the thirtieth year when the period of most rapid height growth is past and the stems have been cleared by natural pruning. A heavy thinning, if made before natural pruning was well started, would result in making the final crop trees too wide-spreading and branchy with short, clear boles. The understory trees prevent the production of epicormic branches on the main stems and continue to some extent the natural pruning.

Crown thinnings can, with a few exceptions, be applied successfully in either pure or mixed stands. There are species, such as Norway spruce and eastern white pine, which in pure evenaged stands do not maintain a good representation of intermediate and overtopped trees suitable to form a satisfactory understory. The ideal conditions for applying crown thinnings are found in a mixed stand, where the final crop trees are of a fast-growing species and the understory is formed by slower-growing, dense-foliaged species capable of furnishing best protection to the site and functioning efficiently as a pruner of the dominant stems.

There are at least two ways of applying crown thinnings. In one, the cutting in the upper crown classes may be so directed as to give more room to as many as possible of the most promising trees on the area, without considering which of these promising trees will continue to the end of the rotation. In the other, a conscious effort may

be made to select the relatively few trees that will form the final crop. In a young stand these trees will be far fewer than the number of promising trees on the area. Each thinning is directed toward giving the few final crop trees (which for ease in recognition may be ringed with paint or otherwise designated) ample freedom on all sides. All trees (mainly codominant and dominant) directly interfering with the final crop trees are removed at each thinning.

Where the final crop trees stand fairly far apart, the first crown thinning, in accomplishing its purpose of freeing the selected trees on all sides, may leave many dominant and codominant trees not interfering for the present with the selected individuals. If the individual trees removed make large holes, this treatment may be too severe. Freeing the crop trees on all sides at each thinning works well provided that holes not over one third the diameter of the crown are opened by the thinning. If larger holes must be made, the worst competitors of the crop trees should be cut and the rest left to be taken out in the next thinning. In the subsequent thinnings all trees (not final crop trees) in the upper crown classes would be removed, leaving eventually only the final crop trees with an understory composed of the lower classes.

For thinning stands of eastern white pine Fernow (1904) advised this method. He recommended the selection at 30 years of 200 trees to form the final crop and the freeing of their crowns by a thinning for a space of 2 to 3 feet on all sides. This would be repeated as often as the crowns touched.

The "Danish thinning" (Oppermann 1926, Sabroe 1926) is an intensive development of the crown thinning principle, which results in high production per acre and in the attainment of exceptionally large diameters at given ages. The reasons for these results lie largely in the intensive application of the principle, in the early start of the thinnings, in the lightness of each cutting, and in the frequent repetition of the cutting. The best trees are kept constantly expanding and are never allowed to slow up their growth rate. In young stands only 2 to 3 years intervene between thinnings. The interval is increased to 4 to 6 years in middle-aged stands and to 6 to 10 years in older stands. The thinnings are begun in young stands 15 to 20 years of age.

It is claimed that, under the Danish thinnings, diameters 50 per cent larger than under other thinning methods can be secured in the same time. The results of medium-heavy Danish-type thinnings in Scotch pine and Norway spruce stands in central Sweden as compiled by Perry (1929) are shown in Table XV. The figures indicate that

47 per cent of the total cubic-volume production during the 120-year rotation was taken out in thinnings. This represented 35 per cent of the total value.

The Selection Thinning Method. Borggreve (1891) developed a method of thinning radically differing in principle from either of the two methods already mentioned. His idea is to take out two classes of trees in the thinning:

1. The largest dominant trees.
2. The overtopped trees likely to die before the next thinning, in order to utilize them before they become a total loss.

The removal of the suppressed trees constitutes a grade-*A* thinning under the ordinary method, but taking out the largest dominant trees is directly opposed to the principles of the low and crown thinning methods, which even in their heaviest cuttings leave the very trees that Borggreve cuts in his first thinning.

The dominant trees to be removed are selected on the basis of their form and the quality of the timber they can eventually produce as compared with their associates. It results usually in the cutting of the largest dominant trees, for such trees in attaining their commanding position have developed large limbs and possibly forked trunks which the smaller dominant, codominant, and intermediate trees have avoided, owing to their more restricted opportunities for growth.

The trees capable of furnishing the largest proportion of clear lumber in the final cut will be found in the intermediate crown class. They have long clear boles which have been thoroughly pruned while still slender. All subsequent growth will have a high percentage of clear lumber. Borggreve in his successive thinnings, removing the relatively poorly formed dominant trees, advances the intermediate trees to the codominant and finally to the dominant crown class — from a subordinate position to a commanding place in the stand with opportunity for rapid growth. In theory trees found in the overtopped class at the time of the first thinning might eventually be advanced to the dominant class. (See Figs. 62, 63, and 64.) The usual procedure in nature is thus reversed.

The success of the selection thinning method hinges upon whether trees that have been crowded and overtopped in the struggle for existence can recover and become thrifty, fast-growing individuals. Undoubtedly the degree to which the process of suppression has advanced is the determining factor in such recovery. The extent to which overtopped and intermediate trees can be expected to develop into first-class dominant trees will vary with the silvicultural habits

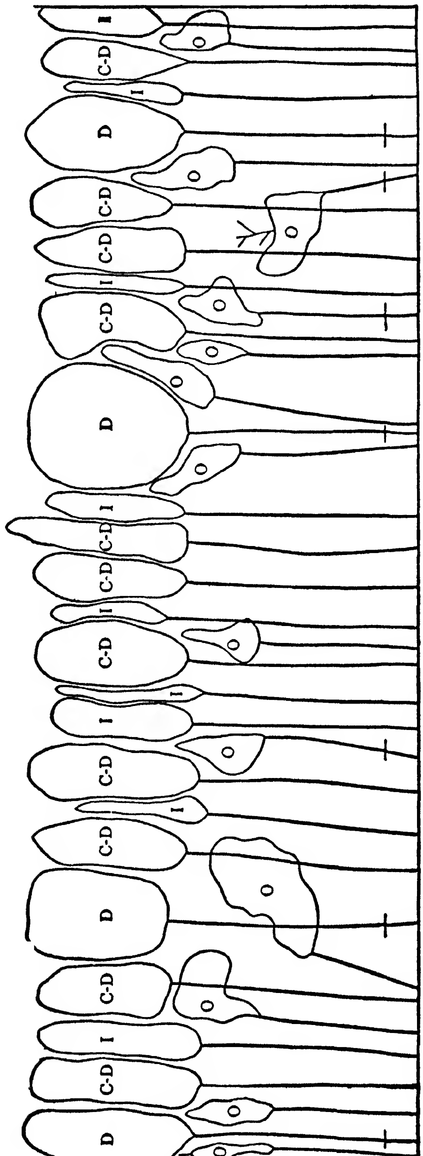

Fig. 62.

A 50-year-old evenaged stand of hardwoods marked for a selection thinning. Trees to be removed are indicated by dashes. The largest dominant trees are cut and in addition a few overtopped trees which would die before the time came for a second thinning. Compare with Figures 52, 53, 54, 55, 56, 60, and 61.

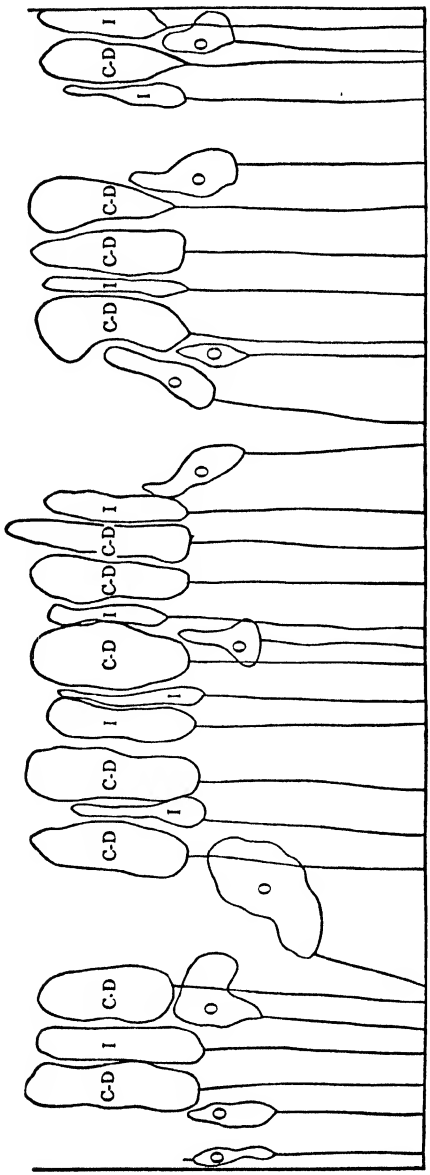

FIG. 63.

The same stand as in Figure 62 after the selection thinning has been made. Compare with the figures illustrating low and crown thinnings.

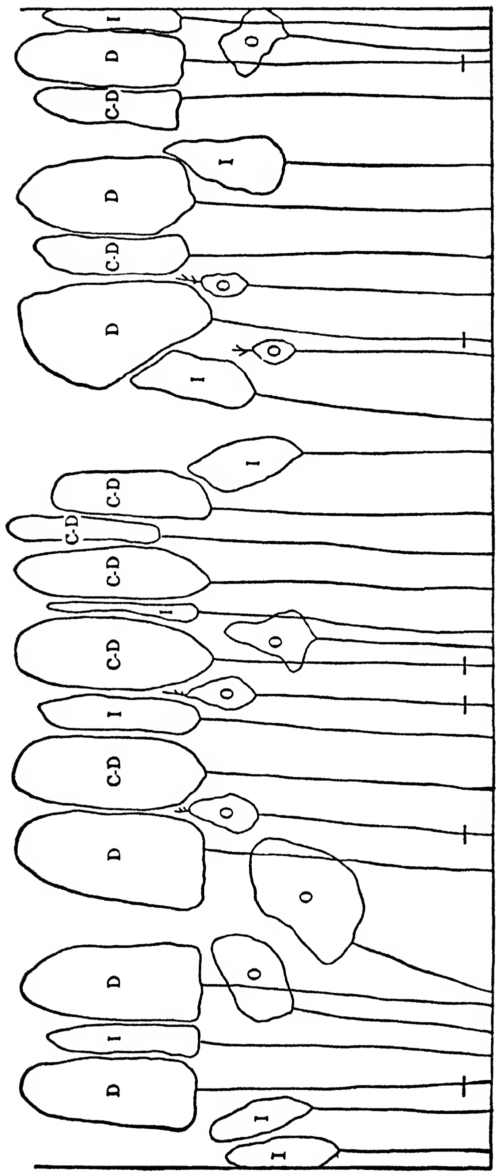

FIG. 64.

The same stand as in Figures 62 and 63, but 10 years after the selection thinning. As a result of taking out dominant trees in the thinning certain trees have advanced from a lower to a higher crown class during the last 10 years. The stand is marked for a second selection thinning, the trees to come out being indicated by dashes. The evenaged form of the stand is maintained, and at the end of the rotation the area will be cut clear.

of the species and with the site and must be determined individually. On better sites there is more opportunity for the application of Borggreve's principle than on poor sites where recovery and rate of growth after thinning take place slowly, if at all.

At first thought it might seem that a series of selection thinnings, if continued long enough, must eventually produce an unevenaged stand and thus be properly classed as reproduction cuttings under the selection method rather than as intermediate cuttings. This is not so. The selection thinnings are continued only until the reproduction period is reached and are strictly intermediate cuttings intended for application in evenaged stands. The overtopped stand serves as a protective cover which has the effect of preventing the establishment of reproduction under any large openings created in the upper canopy.

It is estimated that from 10 to 40 per cent of the volume in board feet of the stand can be removed in a selection thinning. The tendency should be to cut lightly rather than heavily. A high percentage of the volume in board feet should never be removed except in stands where only a few of the larger trees have reached sawable size. In such a stand a light cutting might properly remove a considerable part of the board foot volume. These thinnings cannot be repeated at as short intervals as low and crown thinnings, because of the more severe opening of the upper canopy and consequently the longer time needed to close the gaps. Ten years is considered a short interval between two successive selection thinnings.

The selection thinning method has distinct advantages and disadvantages as contrasted with the other two methods.

The advantages are:

1. The thinning returns a greater profit because the trees cut in the main stand are the largest and ordinarily at that moment the most salable trees in the stand. Lumber may be the chief product as compared with cordwood under other methods.

2. A better quality of timber is produced, because only cleanboled, small-limbed trees are allowed to remain until the end of the rotation.

Among the disadvantages may be mentioned:

1. The rotation must be lengthened to secure timber of a given size. Since the larger individuals are removed in the thinnings and since trees that were at one time in the lower crown classes are developed into the trees for the final harvest, it is evident that a longer time will be needed to produce given dimensions. The average rate of growth of the final harvest trees will be slower than under either

the low or crown thinning method. An increase of 40 to 60 per cent in the length of the rotation should be expected.

2. The growth of the stand is reduced. The removal of the thriftiest dominant trees leaves large openings which are supposedly filled by rapid expansion of trees of inferior crown classes which remain. Only where the species are exceptionally responsive to such treatment, where the site is good, and where the thinnings are kept light, will this assumption hold true. In the average stand repeated use of selection thinnings will reduce the growth and eventually leave a body of trees, formerly in overtopped and intermediate crown classes, which are suffering from exposure to sun, wind, and insects and which fail to conserve the factors of the site.

3. Even more difficulty is experienced than in crown thinnings in felling the large trees and getting the material from the area without injury to or hindrance from the subordinate stand.

4. The fastest-growing, most vigorous individuals are removed at each thinning. This policy is in opposition to the principles of scientific plant breeding. If continued it is likely that ultimately a less vigorous race will occupy the area (Hartley 1927).

Selection thinnings should not be started until good height growth has been attained and natural pruning is far advanced. The best results from such cuttings will be obtained when they are not initiated until between the fiftieth and eightieth years and are used with rotations of 125 to 200 years for the production of high-quality timber. Before the Borggreve cuttings are begun, moderate low thinnings as needed may be employed.

Borggreve's method of thinning was never used in Europe except locally, and the principle is not approved there (Schädelin 1927). For American conditions it may occasionally be of value under special circumstances. In somewhat irregular stands, previously unthinned, and in localities where today only the biggest trees are salable, the method may be applicable. After one or two thinnings it will be better to change over to the silviculturally preferable low or crown thinning methods.

Mechanical Thinning. A fourth method of thinning is to select trees for retention on the basis of an arbitrary spacing and to cut all intervening trees. Mechanical selection of this sort is useful and safe in young crops of high uniformity, averaging 6 to 12 feet high, and also in young plantations. In such stands differentiation into crown classes frequently has not taken place even though the stand is crowded, or if such differentiation has begun there are still many more trees of even size in dominant position than can safely be left.

In stands well advanced in expression of dominance mechanical thinning is a dangerous method, likely if rigidly applied to sacrifice many of the best stems. By taking the best individuals as starting points for application of the spacing the worst results can be avoided. Just to the extent that such selection is made, mechanical thinning merges into one of the other methods.

In the simplest application of mechanical thinning an arbitrary spacing is decided upon and applied rigidly in the field. This permits employment of ordinary labor to do the cutting. The men may even be given a stick, equal in length to the spacing, which when held in a horizontal position will enable them to make the spacing accurate. One arbitrary spacing answers very well in the small crops 6 to 12 feet high, but when the method is employed in dense young stands, containing a range of diameters which may run up to 8 to 12 inches, the spacing has to be varied from place to place in the same stand. A commonly applied criterion for spacing is to take 1½ times the diameter, breast high, in inches as the spacing in feet to be used. The species of tree will undoubtedly influence the multiple of the diameter which should be used. It is likely to be between 1 and 2 times the diameter.

An example of mechanical thinning in densely stocked 40- to 60-year-old lodgepole pine stands, where crown class differentiation had taken place, is reported by Woodhead (1934). The specifications under which he worked provided for 6- by 6-foot spacing where trees were under 6 feet in height, 8- by 8- to 9- by 9-foot spacing where trees were 6 to 12 feet in height, and 10- by 10-foot spacing where trees were 12 to 25 feet in height. It was assumed that it would not be possible to thin again before the end of the rotation. The specifications further provided that dominant and codominant trees, so far as was consistent with average spacing, should be retained and that the quality of trees to be left was to have precedence over rigid regularity of spacing. In other words mechanical thinning was tempered with good judgment. This is the correct way to use the method in all stands except very dense stands of relatively low height, which are usually young. The material cut in this thinning was not merchantable.

The type of thinning advised by Craib (1933 and 1939) discussed on pages 222 and 262 may be classed as a mechanical thinning based, however, on special studies to determine the spacing to be used at each operation. The principle of thinning before competition begins, used in Craib's thinnings, eliminates differentiation into crown classes and makes selection on the basis of spacing rather than crown classes the logical method.

Advantages of Thinnings. The advantages of thinnings as compared with nature's unrestricted competition can be summed up as follows:

1. The length of time required to grow products of the desired sizes can be shortened by means of thinnings. This result is accomplished through an increase in both diameter and height growth, coming as a consequence of eliminating strong competition between individual trees. The trees remaining after the thinning have room to expand their crowns and root systems and to secure large supplies of food, instead of fighting with numerous associates for part of the same total.

The productive energy of the site thus is utilized by a smaller number of trees which are enabled to attain a given size more quickly. It should be emphasized that not only diameter growth is increased but also, to a lesser extent, growth in height. The popular idea that height growth is directly dependent upon and increases with the density of the stand is unsound. Height growth will be greater when the trees are kept in the vigorous condition characteristic of the properly thinned stand than when they are crowded in the unthinned stand.

The free crown surface is greater in the thinned than in the unthinned stand, permitting faster growth. In the unthinned stand the crowns of the trees interlace with a relatively level top surface exposed to the sun. Only occasional dominant trees raise a portion of their crowns above the general level.

Hansen (1937, p. 37) found that thinned plots in jack pine stands had much larger leaf areas per acre than unthinned plots. After a

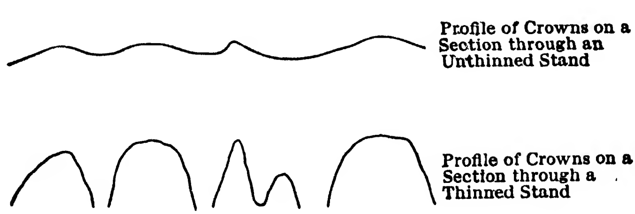

Fig. 65.

Profiles of tree crowns on sections through unthinned and thinned stands.

thinning, cuplike depressions exist between the individual trees, admitting more light both to the crowns of the trees and to the soil. The additional light stimulates activity in the foliage along the sides of the crowns, thus effecting increased growth. (See Fig. 65.)

Greater admission of light has the effect of hastening decompo-

sition of duff and warming up the soil, the result, particularly in northern latitudes, being to increase activity in the soil and to add to the supply of nourishment and increase growth. It is possible that the effect of thinning on soil activity may not always be favorable, if heavy thinnings are made on soil with the mull type of humus layer. However, thinning usually improves humus-layer conditions as well as encouraging an increasing development of roots downward.

Precipitation even in slight rains can reach the soil in greater amount in thinned stands because of decreased interception by tree crowns.

2. Thinnings raise the quality of the product composing the final crop in various ways. Increase in quality is a more certain and important advantage than increase in quantity alone. Trees of poor form, those containing defects, and those of relatively inferior species can be taken out, and the few best trees can be left, upon which growth will be concentrated.

Thinning can be made to assist in the production of wood having the highest possible technical quality. The density of the stand has an important influence upon the specific gravity and hence the technical qualities of the wood produced (Paul 1930). With broad-leaved species, both for ring porous woods such as hickory, ash, and oak and for diffuse porous woods such as sugar maple and yellow-poplar, reasonably heavy thinnings, started after the lower trunk has been cleared of branches by natural pruning, should produce wood of the greatest uniformity and strength. With conifers, when wood of the best strength obtainable for the species is wanted, thinnings should be made, but they should be lighter than for broad-leaved species.

Factors other than strength, as for example the grade of the logs or lumber produced, may be most important for a given species. The severity of the thinnings must be suited to the species and the product desired. Wood of the highest technical quality should be uniform in width of annual ring. Such wood can be grown by thinnings of the correct severity repeated at proper intervals. Intelligent use of thinnings purposely to produce trees of the highest technical quality is still more a matter of theory than of practice in this country. First, more definite specifications must be developed regarding such details as growth rate, uniformity of cross section, size and position of knots, and rate of taper. With this information at hand, tending of the crop, particularly systematic thinning, can assure production of the desired products if they prove worth the cost of growing. In general, the type of trees (upright, straight-stemmed, with sym-

metrical crowns and comparatively uniform growth rate) obtained from a systematically thinned crop will yield timber of higher technical value than those from unthinned stands, even if more detailed specifications have not been available during the long period of crop development.

The larger diameters, and hence widths of lumber, obtainable from thinned stands may heighten the value of the product. Greater crown development following the opening up of the stand by a properly executed thinning does not reduce the clear length of the trees. In fact, although the crown may be lengthened by thinnings, yet equal or greater clear lengths may be produced on account of the greater total height in the thinned stand.

3. By thinnings the total yield both in quantity and in value of product secured from a given area in a specified period will be increased. Various factors contribute to this result.

Thinnings remove and utilize principally trees which in the unthinned stand eventually die in the struggle for existence and may decay before the crop is harvested. Thus the thinnings save what otherwise would be a total loss. In addition, an actual increase in the volume growth per acre should be a result of the thinnings, because of the more vigorous condition and better crown development of the individual trees in a properly thinned stand. Improved soil conditions and a greater amount of available nourishment contribute also to increased production.

Systematic thinnings may increase the total quantity secured during the rotation, from thinnings and reproduction cuttings combined, by 50 to 100 per cent over the production in an unthinned stand.

The yield during the rotation is increased in value for three reasons:

(*a*) A higher quality of product is produced, as explained under heading 2.

(*b*) The thinnings furnish financial returns comparatively early in the rotation. With a slowly maturing timber crop, the time element involving compound interest charges is a vital factor in determining costs of production. Early returns mean higher profits. The total yield during the rotation from thinnings and from reproduction cuttings in stands regularly thinned may be divided into 10 to 90 per cent from thinnings and 90 to 10 per cent from the reproduction cuttings. Thus an appreciable portion of the total production may be removed relatively early in thinnings.

(*c*) The shorter rotation, within which the same-sized products as on a longer rotation in the unthinned stand can be grown, has a

favorable influence on the financial result similar to that exerted by the early returns from the thinnings.

4. Stands may be made more resistant to windthrow and breakage by ice, snow, and wind if thinned, although thinned stands frequently suffer severely from these causes. The expansion of the crown and root system after a thinning increases the power of a tree to withstand these agencies. An illustration of this point is cited by Schantz-Hansen (1939) for red pine. A sleet storm damaged 23-year-old plantations thinned to several different spacings 8 years before the storm. The denser stands were damaged more severely, and the most heavily thinned plot (9- by 9-foot spacing) was least injured.

When expansion of crown and root system does not occur rapidly enough to offset quickly the loss of mutual support caused by opening the canopy, snow and wind injury may not be lessened by thinning. A slender weak tree cannot quickly be converted into a resistant individual by one cutting. The change must come gradually. If a weak tree is too suddenly left unsupported the thinning may result in its being broken or overthrown. Crown thinned stands are likely to suffer more severely from snow than low thinned stands. For one thing the snow may slide off the larger trees onto the trees of lower crown classes left to fill openings.

5. Thinnings keep the stand free of unhealthy and dying trees, in which insects and fungi find the best opportunities for development. The trees remaining in a stand systematically thinned are exceptionally thrifty and do not succumb to the attacks of insects and fungi as easily as the weaker trees in unthinned stands.

6. Thinnings may favorably affect water yield from forested areas by increasing snow storage and lengthening the period of snow melting.

Application of Thinnings. It has already been indicated that thinnings should be started as early in the life of the stand as necessary, but that in practice they often must be deferred on account of the cost until the time when the material removed can pay for the operation. If the owner is willing to invest the cost of the thinning and if the ultimate financial benefits of the operation are clearly discernible, the first thinning should be made as soon as needed. All stands where serious stagnation of growth is threatened as indicated by the live-crown ratio, should be thinned early if the funds can be obtained.

In these early thinnings where the product is not salable the cost of the operation can often be kept low by employing girdling or

poisoning, as described in Chapter X, instead of actually felling the trees. Cromie (1944) has advocated girdling for thinning both pine plantations and mixed hardwood stands in southern New England. Lexen (1939) recommended poisoning for thinning evenaged stands of ponderosa pine.

When the openings made by the preceding thinning have closed, a second cutting should be made. In some cases this may occur as soon as the adjoining crowns touch. More common practice is to allow competition between adjoining trees for a short time before thinning again, so as to encourage height growth and development of a clean bole. The light demands of the species and the type of product wanted will determine whether adjoining crowns are allowed to remain in contact. The interval between cuttings usually is from 2 to 10 years, or even longer in exceptional cases, depending pri-

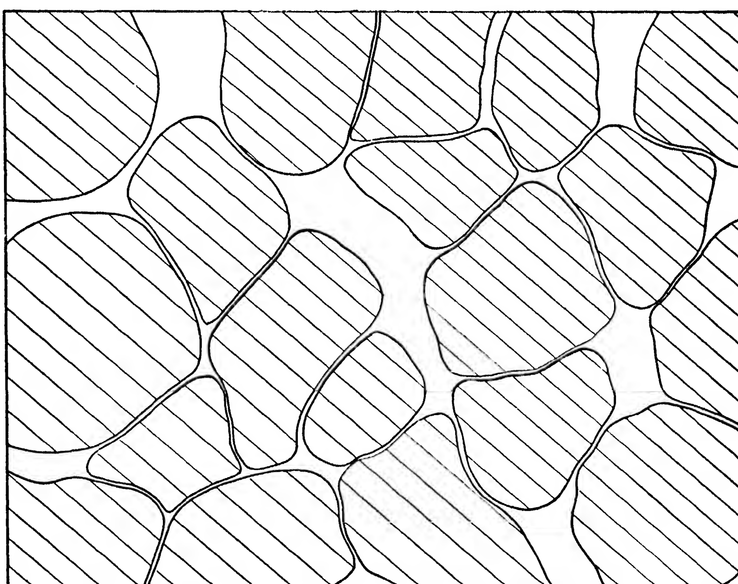

Fig. 66.

The same stand as shown in Figure 59, but 10 years after the *D*-grade thinning was made. The crown canopy is almost complete. The stand is in need of a second thinning.

marily upon the severity of the thinning, the quality of the site, and the inherent ability of the species to take advantage of the increased opportunity for growth. (See Figs. 59 and 66.) Craib (1933) advises 3 thinnings within the first year in black wattle plantations.

On a good site thinnings can be repeated frequently, and each thinning may be relatively heavy because of the rapidity of growth on good soils. It is better silviculturally to make each thinning as light as is consistent with financial requirements and to return often. Frequently, under present economic conditions, thinnings, if made at all, must be heavier and come less frequently than is silviculturally desirable. As the stand grows older the interval between thinnings is likely to lengthen, both because growth may slow up and because the openings in the canopy usually become larger with increasing age of the stand, owing to the greater crown spread of the older trees.

Thinnings should be carried on systematically from early in the life of the stand until the period of regeneration, following a definite policy leading to the production of the desired products. The method of thinning and the severity of the thinnings should be determined separately for each stand.

During the first few decades in the life of an evenaged stand, natural pruning of the stems and rapid height growth should be in progress. Consequently it is better that the first thinnings be relatively light. Later on the trees show a strong tendency for lateral expansion, and the thinnings should be heavier for the purpose of stimulating growth in diameter.

Grade *A* of the low thinning method utilizes only trees that would otherwise be wasted. The growth of the stand cannot be stimulated by removing only those trees which already are conquered in the struggle for existence. Grade *C* is usually needed to secure appreciable stimulation in growth and is generally the grade advised when the low thinning method is employed. Grade *D* for certain products, and for such species as many of the hardwoods, is likely to find increasing use.

Crown thinnings are considered theoretically better than low thinnings and should be employed when possible. Under existing market conditions the low thinning may sometimes be more practical of execution. This is true of many of the mixed hardwood stands in southern New England. In other stands the reverse may be true — the crown thinning being the one which can be applied. Occasionally selection thinnings may be applied under the conditions stated on page 258. Mechanical thinnings apply particularly in first thinnings in dense young stands.

Combining all the methods in the same stand to fit the local variation in conditions encountered is often the wisest course.

Thinnings can well be increased in severity with advancing age in order to satisfy the demands of the trees for greater freedom.

Indeed, because of the larger crown spread of the individual trees in an older stand, bigger gaps must be left if any thinning is made.

In applying thinnings the danger from windthrow and breakage must be kept in mind. Any stand, by systematic thinning, can be made comparatively resistant to storms, if the operation is initiated early in life. The development must be gradual. If a stand is thinned too heavily at first, all the entire remaining trees may be lost. Dense stands of tall, small-crowned trees which have gone for years unthinned reach a stage when it is dangerous to make even a light thinning. Timber like this ordinarily must be left untouched until it is ready for regeneration. Danger of windfall after thinning is greatest on wet ground, thin soil, and exposed sites and with shallow-rooted species.

Plantations require thinning soon after they close. So many individuals in a plantation are all of about the same size and vigor when they meet that an even but severe struggle takes place, which is likely to leave all the contestants alive but seriously weakened. Therefore, if early thinnings are impracticable, the spacing in the plantation should be wide.

In cottonwood plantations, containing 700 to 1200 trees at the age of 1 year, MacDonald (1924), writing of conditions in Iowa where the natural forest area is low and intensive management is profitable, advised thinnings at 8, 15, and 25 to 30 years, with a final harvest of the stand in the thirty-fifth year.

Ashe (1915), Cope (1923), and Mattoon (1926) have all recommended the application of low thinnings in loblolly pine stands. Ashe and Mattoon indicate that thinnings of the selection type also can sometimes be employed to advantage. Ashe restricts selection thinnings to permanent loblolly pine sites and to young stands (25 to 30 years), because at this age the codominant and intermediate trees still have the ability to fill the gaps left by removal of dominant trees; Mattoon states that the low thinnings are better and "should always be used in thinning young pines." Whether thinnings of the selection type can be employed repeatedly in stands of loblolly or other southern pines is open to question. Southern pines do not maintain a sufficient number of trees in the lower crown classes to fill completely the gaps made by cutting the dominant trees. Permanent gaps are created in which reproduction becomes established and has opportunity to develop. The thinning then is in reality a reproduction cutting of the selection type. As a result an unevenaged stand is maintained. The procedure is well illustrated in a diagram by Mattoon (1927, p. 18).

Chapman (1942, pp. 87-98) recommends for loblolly pine in Arkansas and Louisiana that thinnings begin as soon as the live-crown ratio of the crop trees begins to fall below 40 per cent. He advises removing 50 per cent of the crown cover in the first thinning, by making openings of the same area as the average of the crowns of dominant trees left as crop trees. The number of crop trees left is intended to stock the stand, preferably with a spacing of 12 by 12 feet. Since every crop tree is released on all sides and only unmerchantable overtopped trees are left, the thinning is essentially a severe *D*-grade thinning. Because of the rapid expansion in width of loblolly pine crowns the relatively large openings are rapidly covered, and another thinning is usually needed at the end of 5 years.

Ashe (1913) made an intensive study of thinning practice in shortleaf pine and brought out in detail the financial aspect of systematic thinnings.

Stands of eastern white pine in New England were among the first in the United States to receive thinnings. Low thinnings have been customary in naturally reproduced stands of this species. This method is better adapted to the previously unmanaged, pure stands of white pine than the crown thinning method. However, the first and probably the second thinnings in eastern white pine plantations should be crown thinnings or possibly selection thinnings because some of the largest trees are the most badly deformed by the white pine weevil (*Pissodes strobi*) and must be removed. After these early thinnings low thinnings will be the best. It is practically impossible in pure stands of eastern white pine to find and keep alive the lower-class trees whose presence characterizes the crown thinning method.

One of the few places in this country where repeated thinnings have been made is located near Keene, N. H. Here a series of plots in a stand of eastern white pine was thinned 6 times in 30 years (Hawley 1936) by the low thinning method, *C*-grade. In addition, beginning with the second thinning in 1915, the basal area per acre was reduced at each thinning to approximately 100 square feet per acre. This is a definite expression of what is meant by a *C*-grade thinning in eastern white pine. With practice a thinning of this severity could be marked without the necessity of measurements, except occasionally, to check results of the marking. Under the conditions encountered with eastern white pine, it should prove an entirely practical way of securing the same degree of thinning when marking is carried on by different men. The volume in feet, board measure, removed in each of the 6 thinnings is shown in Table XIV.

TABLE XIV

VOLUME PER ACRE IN FEET, BOARD MEASURE, REMOVED IN THINNINGS IN EASTERN WHITE PINE

Age of stand, yr.	*Year of thinning*	*Volume from trees less than 10 inches in diameter, bd. ft.*	*Volume from trees 10 inches and over in diameter, bd. ft.*	*Total volume, bd. ft.*	*Percentage of volume cut, bd. ft.*
38	1905	2,820	180	3,000	20
48	1915	5,744	628	6,372	32
53	1920	1,084	356	1,440	8
58	1925	2,446	1,822	4,268	20
63	1930	426	2,348	2,774	12
68	1935		3,756	3,756	15
Total		12,520	9,090	21,610	

There should have been a thinning in 1910 as well as at least two thinnings before 1905. As compared to the unthinned portion of the stand very favorable results were secured from the thinned part. All the 104 trees per acre remaining after the sixth thinning in 1935 were symmetrical in crown form, straight boled, and vigorous. The thinned stand had produced more total volume, with a bigger proportion in the more valuable size classes, in the 30-year period. With approximately half the growing stock per acre it had a higher current growth, with growth put on trees of larger size. Nearly 22,000 feet, board measure, per acre of timber worth at least $100 standing had been taken from the thinned stand in contrast to none from the unthinned. Continuation of the thinning schedule for another 20 to 30 years appeared profitable, but unfortunately the entire forest in the vicinity — thinned, unthinned, second growth, and dense old growth — was destroyed in the hurricane of 1938.

Cottrell (1930) developed logging technique and markets for small products, such as shade-tree stakes 2 to 3 inches in diameter, which made possible profitable thinnings in Atlantic white-cedar swamps in New Jersey. Thinnings are always difficult to apply at a profit in swamps because of the unfavorable conditions for cheap logging. The logging difficulties in this case were solved by using a 24-inch-gauge steel mine track which could be handled in 15-foot sections and could easily be laid where wanted. A small car pushed by hand completed the equipment for removal of the products to the edge of the swamp. Cedar products worth $200 to $500 per acre were cut in these thinnings which netted an average profit of $37 an acre for the areas thinned. As yet there are few examples in this country of thinning practice where such material (probably averag-

ing less than 3 inches in diameter) can be removed and marketed at a profit.

Examples illustrating the application of thinnings systematically throughout the rotation cannot be found in American forests because of the short time that thinnings have been used. In order to bring out the relations which exist between the stand as a whole and the portions removed in the thinnings, as regards age, basal area, volume per acre, number of trees, and value, there is presented in Table XV an example taken from central Sweden in the form of a yield table

TABLE XV

YIELD TABLE FOR AVERAGE-QUALITY SITE, PINE, AND SPRUCE, CENTRAL SWEDEN[1]

Medium to heavy Danish-type thinnings have been applied.

Reproduction method used: clearcutting with scattered seed trees and sowing in prepared spots.

The values are on a per acre basis.

						Removed in Thinnings during Foregoing 10 Years		
Age, yr.	*Average height, ft.*	*Basal area, sq. ft.*	*Total volume, cu. ft.*	*Total number of trees*	*Value*	*Number of trees*	*Volume, cu. ft.*	*Value*
20	18	41	429	3030	$ 5.17	....	....	....
30	27	63	887	1275	30.45	1755	128	$ 0.76
40	34	76	1401	720	66.63	555	214	5.72
50	43	87	1873	515	109.83	205	314	13.50
60	48	96	2302	420	156.92	95	357	19.98
70	53	101	2674	348	207.14	72	386	25.49
80	57	107	3003	291	258.87	57	386	29.16
90	60	110	3274	251	310.07	40	386	32.40
100	63	112	3489	219	359.92	32	386	35.32
110	65	114	3645	190	404.78	29	386	38.23
120	66	116	3745	170	445.39	20	386	40.82

	Thinnings in Percentage of Total Production		Total Production	
Age, yr.	*Volume, cu. ft.*	*Value*	*Volume, cu. ft.*	*Value*
20	....	....	429	$ 5.17
30	12.6	$ 2.4	1015	30.76
40	19.6	8.9	1743	73.11
50	26.0	15.4	2529	129.87
60	30.6	20.3	3315	196.88
70	34.5	24.0	4073	272.59
80	37.4	26.8	4788	353.48
90	40.0	29.1	5445	437.08
100	42.2	31.2	6046	521.74
110	44.7	33.1	6588	605.33
120	47.0	35.1	7074	686.76

[1] Taken from Perry (1929, pp. 46–47).

TABLE XVI

THINNING SCHEDULE FOR *Pinus patula*

	Site I				Site II				Site III			
		Number of trees per acre				*Number of trees per acre*				*Number of trees per acre*		
	Age, yr.	*After thinning*	*Removed in thinning*	*Mean D.B.H. of felled trees, in.*	*Age, yr.*	*After thinning*	*Removed in thinning*	*Mean D.B.H. of felled trees, in.*	*Age, yr.*	*After thinning*	*Removed in thinning*	*Mean D.B.H. of felled trees, in.*
1st thinning	8	300	200	6.2	6	300	200	—	6	180	120	—
2nd thinning	12	200	100	8.4	14	190	110	7.1	20	120	60	9.0
3rd thinning	18	130	70	11.4	25	130	60	12.0	30	85	35	11.0
End of rotation	30	0	130	18.0	40	0	130	18.0	50	0	85	18.0

for Scotch pine and Norway spruce, the former making up 70 to 80 per cent of the volume. Study of this table should be of assistance in making clear the results secured from a series of thinnings repeated throughout the rotation. The data have been taken from a larger table published by Perry (1929, pp. 46-47).

One of the best examples of a systematic thinning program is that developed by Craib (1939, pp. 117-120) for the conifer plantations in South Africa. These plantations of yellow pines already exceed 200,000 acres and should be an important source of forest products for a region with a low percentage of natural forests. Craib's program is not just a paper plan but is being applied in actual practice. The details of the thinning schedule for one of the several planted pines, namely *Pinus patula*, will be briefly discussed.

The basis for Craib's recommendations was in the methods described by O'Connor (1935), which involve the principle that thinning be applied before competition between adjoining trees starts. The data obtained led to the conclusion that *Pinus patula* should be planted at a 9- by 9-foot spacing on site quality I and II, requiring approximately 500 trees per acre, and 12- by 12-feet on site quality III, requiring approximately 300 trees per acre. The purpose which determines the original stocking and the numbers left at each thinning is to secure trees of the same diameter (18 inches breast high) on all 3 sites at the end of the rotation. The thinning schedule then works out as indicated in Table XVI.

If this table were applied to most of the species under usual conditions in this country, it would appear that on site II and III areas the number of trees would be so reduced by the thinnings as to leave the stand only partially stocked. Craib believes that because of wide root spread this will be true only up to about the eighth year and is not a serious disadvantage. He admits that volume production will be less than under a former, less heavy, thinning schedule, but he shows that total value will be 10 per cent higher on site II and 100 per cent higher on site III because trees of bigger diameters are obtained.

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CHAPTER XII

IMPROVEMENT AND SALVAGE CUTTINGS

Improvement Cuttings. Improvement cuttings are cuttings made in stands past the sapling stage for the purpose of improving their composition and character by removing trees of undesirable species, form, and condition occupying dominant positions in the main crown canopy. These inferior stems are removed only when such action will assist better stems or species. This point should be kept clearly in mind in applying improvement cuttings.

In principle an improvement cutting is almost identical with a selection thinning. One distinction between the two is that an improvement cutting will be applied chiefly for the removal of undesirable species, whereas the selection thinning is used for removing the larger trees which are inferior in form to adjoining codominant or intermediate individuals. Another distinction is that selection thinning, like all other thinnings, is made within an evenaged stand or group whereas an improvement cutting finds application in both regular and irregular stands. In evenaged stands improvement cuttings are needed only where cleanings were not made early in the rotation. Most unmanaged stands containing more than one species are in need of such a cutting.

In a stand of this kind trees of undesirable species or poor form are likely to be in dominant position, overtopping more valuable individuals; also many intermediate and overtopped trees that have been overcome in the struggle for existence could be cut to advantage, if merchantable. The removal of dominant trees of undesirable species and poor form is like a cleaning, while the cutting of the trees of lower crown classes in a measure resembles a thinning (see Fig. 67). In the selection of the trees to be taken out in the combined operations, the principles laid down for the making of cleanings and thinnings should be followed.

One improvement cutting may be sufficient to regulate the mixture in the stand; if so, subsequent cuttings will be in the nature of thinnings. On the other hand there may be so many trees of undesirable species or poor form in the dominant stand that their removal all at one time would result in too severe an opening up

Inferior Species		Valuable Species	
A = Aspen.	G-B = Gray Birch.	R-O = Red Oak.	W-A = White Ash.
D = Dogwood.	S-M = Soft Maple.	H-M = Hard Maple.	W-P = White Pine.

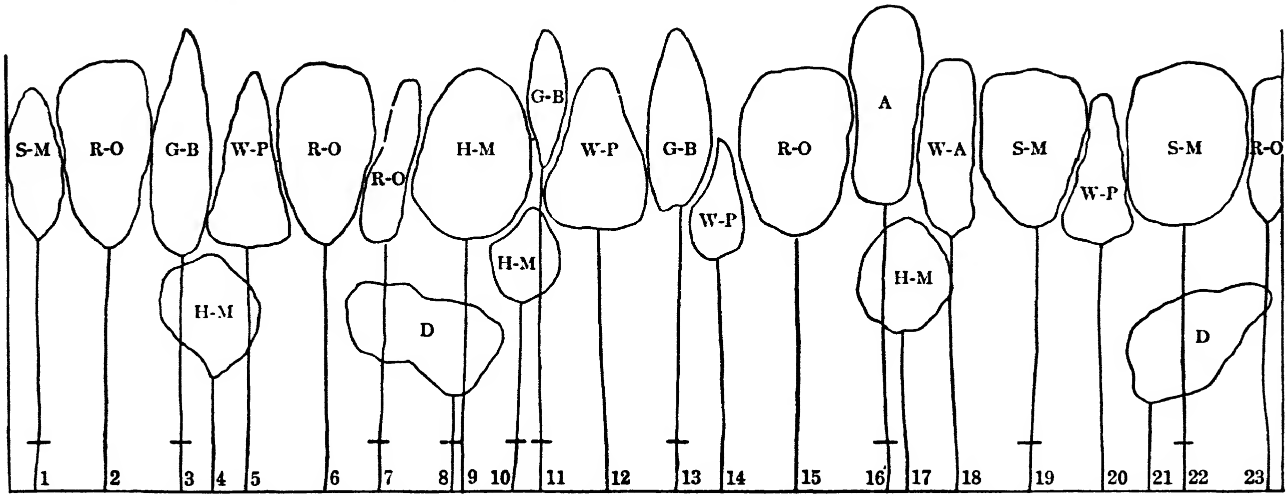

Fig. 67.

A 50-year-old mixed stand marked for an improvement cutting. The trees to be removed are indicated by dashes. The removal of trees 3, 11, 13, 16, 19, and 22 constitutes a cleaning because dominant inferior species are cut to favor more valuable individuals. The cutting of trees 1, 7, 8, and 10 corresponds to a *C*-grade low thinning. Trees 4, 14, 17, and 21 are left standing to fill openings created by the removal of dominant trees of inferior species.

of the canopy. A second and even a third improvement cutting may have to be made before the mixture is satisfactory.

In stands managed from early youth cleanings made at the proper time will eliminate the necessity for improvement cuttings at a later date. Where economic conditions prohibit early cleanings there will be opportunity for improvement cuttings. In contrast with cleanings, improvement cuttings yield material always large enough for cordwood and hence may be profitable.

It is much better from the silvicultural standpoint that cleanings rather than improvement cuttings be employed. Where undesirable species are allowed, until of salable size, to occupy a dominant position for a series of years during which severe competition between individuals is in progress, the growth of the overtopped but more valuable species will be checked and their development seriously curtailed.

Because the forests in this country have been in the past without skillful treatment there are found today millions of acres in need of improvement cuttings. A large percentage of these areas lie in relatively inaccessible regions where cordwood, usually the chief product obtained in improvement cuttings, has a negative value. Under such circumstances girdling or poisoning is frequently used, instead of the felling of the trees to be disposed of. Girdling and poisoning of standing trees have been discussed under liberation cuttings, page 209, and what has been said there applies also to improvement cuttings.

It will be recalled that the principal distinction between liberation and improvement cuttings is that liberation cuttings release young growth not past the sapling stage and much younger than the trees cut whereas improvement cuttings release trees past the sapling stage which may or may not be younger than the trees cut.

Improvement cuttings have been applied for a longer time in the Northeast than elsewhere in the country, particularly in mixed stands of spruce and fir overtopped by hardwoods of poor quality and frequently unmerchantable. Experience with these species indicates (Bryant, *et al.* 1930) that improvement cuttings accomplished by girdling are the most profitable where softwood timber of merchantable size is released 10 or more years before logging. Such cuttings will often pay for themselves through the increased growth of the trees released within 5 to 10 years. Westveld (1936) describes the results, 30 years after its initiation, of an experiment in New Hampshire in which a dense understory of unmerchantable red spruce, 2 to 6 feet in height, was released, by two successive cutting

and girdling operations, from a 60-year-old stand of northern hardwoods. On a heavily girdled area the volume of spruce pulpwood amounted to 11.4 cords per acre; on a moderately girdled plot it was 4.9 cords, and on the check area, on which no girdling was done, it was only 0.5 cord of pulpwood per acre. This difference in yield is attributed entirely to the improvement cutting. The cost of the moderate girdling is estimated at $2.00 and of the heavy girdling at $2.60 per acre.

Improvement cuttings are made, as previously stated, not only in evenaged stands and groups but also in stands of irregular form. In fact their widest application is found in forests so irregular that an immediate application of one of the high-forest systems (as for instance the shelterwood method) is out of the question. A period for the improvement of the forest must be set aside, during which improvement cuttings are made.

The irregularity in stand structure is not the main factor that makes improvement cuttings applicable. Even more important is the accumulation of undesirable trees which are in partial or full possession of the area. Various causes have brought about this situation, but in most parts of this country cutting of the forest, one or more times, for the best species and finest individuals is responsible. Other results of former mismanagement, such as injuries from fire, are also influential. Improvement cuttings are almost always needed in building up a badly managed and depleted forest. Ordinarily the undesirable trees are remnants of a previous stand and are in dominant position and consequently older and bigger than the more desirable trees, which in culled forests often originated after the cuttings.

Where improvement cuttings are applied in irregular stands, the improvement of the existing crop is the primary consideration and reproduction is a secondary matter often not wanted at all. Exceptions to this statement occur when large holes are created by the removal of trees with wide-spreading crowns and sufficiently dense foliage to have prevented young growth from developing underneath. Here reproduction would be needed to fill the opening. This situation is not so frequently encountered as might at first thought be expected, since there ordinarily are better individuals than those removed already established. It is the purpose of the improvement cutting to afford these better individuals an opportunity to develop and take over the space at the moment occupied by the undesirable trees.

Usually the stands in need of this type of improvement cutting

contain inferior individuals of an old age class, interspersed with middle-aged timber or young growth. The types of tree usually removed (if thereby better trees will be helped) in an improvement cutting include:

Overmature trees.
Crooked, extremely limby, or otherwise badly formed trees.
Trees seriously injured by fungi, insects, or other causes.
Inferior species.
Climbing vines.

All trees of the above classes may be removed in the improvement felling, provided that the ground is not unduly exposed and the density of the stand is not injuriously reduced. Often it will be impossible to remove at one improvement cutting all such trees and still maintain the desired density of stocking. If so, the improvement cutting should be repeated at an appropriate interval, usually not less than 10 years.

Even though material of merchantable size is obtained in an improvement cutting, it does not necessarily follow that these operations are profitable in the sense that the current revenue received exceeds the expenditures. So many of the trees cut may be entire or partial culls or contain very low-grade material that often the operation cannot finance itself. To reduce expenses girdling and poisoning are likely to prove preferable to felling the trees. The investment of funds, in reasonable relation to expected future returns, is thoroughly justified by the great improvement in quality of production in stands so treated.

Reynolds (1939) describes improvement cuttings for shortleaf and loblolly pines in Arkansas. He considers that all types of stands whether virgin, second growth, or old field contain undesirable trees, both pine and hardwood. So far as possible, the inferior species and crooked, defective, or very limby trees to be removed should be cut into products that will pay the costs of extraction. If more is lost on a tree than it costs to girdle, girdling is recommended at a cost of less than 5 cents per tree for trees that occupy on the average $\frac{1}{10}$ acre apiece. Under the market conditions existing on one area, the pine put into pulpwood and the hardwood put into chemical wood returned a slight excess of revenue over the cost for nearly all trees. Only the worst individuals had to be girdled.

In India the large areas of mismanaged forest, with irregular stand structure and an accumulation of inferior trees, have necessitated frequent improvement cuttings. As applied in India (Champion and

Trevor 1938, pp. 278-281, 341-343), improvement cuttings function both as a silvicultural operation in tending the crop and as a provisional silvicultural system that will later lead to management under one of the standard methods (for example, shelterwood or selection). In execution the improvement cuttings, with revenue as a secondary consideration, remove dead, dying, overmature, and badly formed trees and individuals of poor species interfering with those of a better species. Regeneration follows where adequate openings are made.

Timber Stand Improvement. This term within recent years has become widely used and should be considered at this point. "Timber stand improvement" includes all cuttings, not a part of a major harvest felling, made during the life of a forest stand for the general purpose of improving the stand as regards composition, condition, and rate of growth. In other words it is synonymous with "intermediate cuttings." Sometimes timber stand improvement has been confused with improvement cutting, which is a less comprehensive operation.

With the establishment of the Civilian Conservation Corps in 1933, a great reservoir of manpower was made available to state and federal organizations managing forest lands. Labor paid by relief funds also became available. Part of the labor so obtained was directed into a variety of silvicultural operations, which earlier had not been undertaken because of lack of funds for such investments. Timber stand improvement, as the various cleaning, thinning, salvage, and improvement cutting operations and pruning came to be called, received a tremendous impetus, particularly on the National Forests, where little of this work had previously been carried on (Pearson 1939, Anonymous 1933*a* and *b*). Hundreds of thousands of acres have been treated.

While the funds for such work are now curtailed, it is probable that in periods of unemployment stand improvement will again be developed on a big scale. Whether all the work done in the past was justified on the basis of future values developed thereby is doubtful. With more time to plan ahead and greater familiarity with all aspects of the problem a more careful appraisal can be made in selecting future projects.

Timber stand improvement, as conceived and applied over a 10-year period, has been an important forward step in the application of silviculture in the forests of this country.

Salvage Cuttings. Cuttings made for the purpose of removing trees killed or damaged by various injurious agencies are termed

"salvage cuttings." "Damage cuttings" is a synonymous term. (See Fig. 68.)

Damage in the forest due to fungi, insects, fire, wind, snow, and other agencies is occurring continuously and frequently reaches serious proportions in a given stand. The removal of trees injured by their neighbors in the struggle for existence does not constitute a salvage cutting but falls under thinning.

Salvage cuttings, as the name indicates, attempt to utilize the injured trees with the idea of minimizing the loss. No skill is re-

A = Fire scars. B = Stagheaded tree. C = Canker. D = Killed by insects.

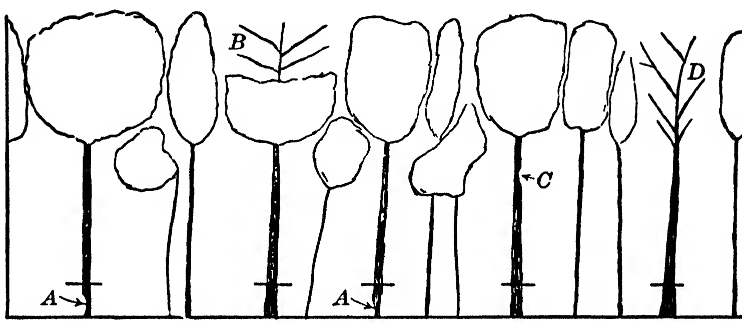

FIG. 68.

A stand in need of a salvage cutting. The injured trees are indicated by dashes. So many trees require cutting that the remaining stand will be irregular and open. Reproduction will be needed to fill the openings.

quired in selecting the trees to be taken out other than ability to recognize those that have injuries necessitating removal. The severity of the cutting depends entirely upon the proportion of the stand occupied by the damaged trees. On this basis a salvage cutting may range from a light partial cutting to a clearcutting.

Salvage cuttings are not made unless the material taken out will at least pay the expense of the operation. Exceptions to this statement occur when it becomes essential for the safety of the surrounding forest to remove unmerchantable trees attacked by insects or fungi.

Even though the damaged material can be salvaged at a profit, the injuries which made the operation necessary ordinarily occasion an ultimate loss. This is true especially when stands in the first half of the rotation are damaged. The loss is due partly to deterioration of the injured trees before being salvaged, partly to a reduction in the density of stocking, with the possibility that a portion of the area may be unproductive, and partly to the cutting of the injured

trees before they have attained the size and can furnish the products desired by the owner.

Wherever extensive injury has occurred, provided that the condition of the stand permits, reproduction cuttings should be initiated and a new stand established. It is better to remove the remaining healthy trees along with the damaged ones than to leave them in too open a stand. Nearly all heavy salvage cuttings are followed by reproduction of some sort or by a growth of grass, weeds, or brush. Where fire was the source of the damage the subsequent reproduction is likely to be of undesirable species.

Artificial regeneration is often needed after a salvage cutting.

Even though fire, fungi, insects, or wind may be looked upon as accidental factors, yet injuries from these causes are of such common occurrence as to make salvage cuttings an expected and frequently needed operation.

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CHAPTER XIII

PRUNING

Purpose of and Need for Pruning. Pruning is the operation that removes branches from standing trees. In forestry two types of pruning are recognized; natural or self-pruning, and artificial pruning. Natural pruning functions slowly during the life of the forest crop, brought about by the reduction of light in the interior of the stand as the trees join crowns and increase in height. Artificial pruning accomplishes quickly the removal of branches from chosen portions of the stem. The purpose of resorting to artificial removal, instead of waiting for nature to perform the task, is to increase the quality and value of the crop ultimately harvested.

For the production of clear lumber the early removal of all limbs from a portion of the tree bole is essential. As already stated this may be accomplished in the forest naturally by means of the competition among the individual trees. In fact good natural pruning is the chief advantage of dense stands. Under certain conditions nature's process is fully satisfactory and produces a high percentage of clear lumber. However, it requires a dense stand, with correspondingly slow growth of the individuals and a comparatively long rotation to accomplish nature's results. For most of our commercial species, rotations of at least 150 years are required to produce reasonable amounts of clear lumber, if rèliance is placed on natural pruning.

Nothing better can be expected where silvicultural practice must be crude and extensive. When intensive methods are possible, applied silviculture aims to reduce the density of the stand found in nature, with the purpose of obtaining a reduction in the length of time necessary to produce lumber of a given size (see chapter on thinnings). The long rotations, which, in the virgin forest, have accumulated stores of clear lumber developed under nature's method of pruning, cannot be tolerated in the managed forest because of their poor financial showing. In order to produce a reasonable percentage of clear lumber on a short rotation in stands kept growing at a fast rate, artificial pruning usually will be required. In plantations the argument has special weight. Here in order to save expense trees are set out at the rate of 500 to 2500 per acre, with the average num-

ber probably less than 1000. As compared with the stands of several thousand trees per acre frequently starting on areas naturally reproduced, this is a small number and results in stands not very densely stocked. Such plantations, if they are to yield clear lumber in appreciable amount, demand artificial pruning.

The inherent ability of the species to prune naturally is of fundamental importance in determining the need of artificial pruning. Certain species prune more quickly and completely than others. For example yellowpoplar has the inherent characteristic of pruning quickly and thoroughly and does not need to be artificially pruned. Douglas-fir self-prunes so poorly as to require either artificial pruning or a rotation of 150 years.

No matter how early pruning is begun, whether natural or artificial, there will always be found a central knotty core in the tree or log. The clear wood obtained will be in a zone surrounding this knotty core. Even the old trees of the virgin forest all have knotty cores in the center, which will be bigger in diameter, on the average, than those found in trees artificially pruned. In artificial pruning one of the principles is to restrict this central knotty core to a small diameter, thereby favoring the development of a relatively wide zone of clear wood, even on the short rotations practicable in forest-crop production.

Effect on the Tree. Artificial pruning of tree limbs has sometimes been criticized on the grounds that it harms the tree. This criticism is almost groundless as far as properly conducted pruning is concerned. Pruning is done to increase the value of the tree.

Careless pruning can do much mechanical injury to the bole, leaving wounds extending through the bark to the cambium layer and also into the wood. These wounds come from blows against the stem, from cuts, and from tearing of bark and wood. Such crude injuries are unnecessary and can be avoided.

An antiquated idea that is still sometimes advanced is that artificial pruning causes loose knots in the lumber. Actually artificial pruning has nothing to do with the formation of loose knots. Loose knots can exist only in the central knotty core which was not pruned. When a branch dies the stem continues to add new wood around the dead branch, but no longer do the stem and branch grow solidly together. Hence when such portions of the tree are sawn into lumber and dried, the knots may become loose and in thin lumber may fall out, leaving open cavities in the boards. Artificial pruning cuts off the dead branch and renders impossible the development of any more knots of any kind from that branch.

Possible injuries from artificial pruning may consist of bark pockets, pitch pockets, and discoloration of the wood. Bark and pitch pockets may be found at the end of the pruned-off branch stub, where the callus in healing over the cut has caught and enclosed patches of bark instead of pushing all of it out of the way. With some species deposits of pitch are made over the stub and are frequently covered over by callus. Both bark and pitch pockets will be located close to the branch stub, extending outward in radial width a fraction of an inch. In computing diameter of the central knotty core in pruned trees allowance should be made for these probable extensions of the knotty core, the amount depending upon the species. For eastern white pine an addition of 2 inches to the diameter of the knotty core at the time of pruning is considered ample. This allowance of an inch on each side of the core should be enough to include all bark and pitch pockets likely to be formed.

Artificial pruning may result in some discoloration of the wood close to the pruned stub. Such discoloration is frequently entirely unrelated to any decay, being in reality a chemical change brought about by exposure of the wood to the air. As an illustration, Hawley and Clapp (1935) in studying dissected pruned trees found two types of discoloration. The common type was a red-brown tinge penetrating the new wood around the stub for 0.1 to 0.5 inch. It was considered to be due to filtration of soluble substances from stub to new wood or to possible oxidation of substances already present. Once the wound is closed this type of discoloration is not expected to spread. On a small percentage of the samples a second type of discoloration was observed. This was a gray-green tinge going 0.3 inch into the new wood and caused by a sap-staining fungus that entered the stub before it had completely callused. Once the supply of air and moisture is cut off by closing of the callus this sap stain cannot spread. Discolorations are likely to be more frequent and pronounced in hardwoods than in softwoods.

What injury there is from bark and pitch pockets and discoloration as a result of artificial pruning is found only along the outside of the central knotty core and has the effect of somewhat enlarging its diameter. These small additions to the central knotty core will be of far less importance than the defects that would occur throughout the entire log if no artificial pruning was done. The central unpruned core will, irrespective of artificial pruning of the tree, contain material of low grade and should be sorted out from the clear lumber coming from the outer zone, grown after the pruning.

Where it can be shown that artificial pruning will be the cause of

admitting dangerous insects or plant pests into the tree, the operation should not be performed unless control measures are taken. Before advocating pruning for a given species this matter should be investigated. If the pruning is properly done, no injury from this source is anticipated to eastern white pine in the Northeast, for which species and region artificial pruning has been investigated more thoroughly than for other American trees. However, Spaulding, MacAloney, and Cline (1935) found that, where pruning of limbs 3 inches or larger in diameter was undertaken, *Stereum sanguinolentum*, a dangerous fungus capable of ruining the tree for lumber, often gained entrance. Limbs of this size contained a heartwood center. Through the heartwood dangerous fungi may gain entrance where they could not do so through sapwood. With eastern white pine, limbs 2 inches and less in diameter are not likely to have any heartwood. Forest pruning in any event should be restricted to small branches. Where cuts more than 2 inches in diameter are made, it would be advisable on eastern white pine to coat the surface with a mixture of dry Bordeaux and linseed oil in equal parts by weight.

The possibility that pruning wounds will be infected by dangerous fungi may be influenced by the condition of the limb as well as by its size. Both dead and live limbs may be pruned. Dead limbs provide a means of entrance into the living tree for fungi and insects. It is evident that the tree will not be harmed but will on the contrary be benefited by the removal of limbs already dead. They are in themselves defects and so continue as long as allowed to remain. The pruning of such limbs allows callus to grow quickly across the stub and shortens the time in which the dead limb is exposed to attack.

However, the pruning of dead limbs only will not solve the problem of producing a satisfactory percentage of clear lumber on 40- to 80-year rotations in most plantations as spaced in this country. A judicious amount of live pruning will be necessary. Even in naturally reproduced stands considerable live-limb pruning should be done in order to clear the lower stem of branches at an early period.

Cutting of live limbs might increase the possibilities of injury because the cut surface exposes living wood otherwise not exposed, conceivably affording opportunity for the entrance of insect and plant pests. As already stated, for the American species so far studied, this appears more of theoretical than of practical importance if the pruning is confined to small limbs which do not contain heartwood. The small pruning wounds on the vigorous trees selected for pruning have not proved to be entering points for dangerous enemies.

Live wounds in some species are quickly covered by exudations of pitch. Even where no such protective covering is provided, callus formation is relatively fast and within a few years the wound has been completely occluded. The vigor and rate of diameter growth of the individual tree at the time of pruning undoubtedly are of great importance in determining how rapidly the pruning cuts heal.

The stubs of dead limbs do not heal as fast as cuts through live limbs. Recognizing this fact, Curtis (1936) has attempted, by purposely wounding the live wood around dead stubs, to stimulate the rate of callus formation and thus shorten the time necessary to cover the stub. He wounds the adjoining live tissue by making the pruning cut exceptionally close to the stem, 1/16 to ⅛ inch closer than customary. This involves extra effort on the part of the workman, and whether it increases the cost out of proportion to the benefits gained is not as yet determined. Slightly faster covering of the extra-closely pruned stubs was found by Curtis. It is not clear whether this was due to the stimulus in callus formation of wounding live tissue or to the fact that the callus did not have to creep up the 1/16- to ⅛-inch stub before starting to spread over the surface of the stub. Adams and Schneller (1939), working on the same problem, found it difficult to prune close enough to wound the cambium in pruning dead limbs. Although they found somewhat quicker start in callus formation, the extra-close pruning cost about 23 per cent more than the standard.

Improper pruning, by the removal of too many live limbs at one time, may seriously reduce the crown surface available for carrying on photosynthesis, disturb the balance existing between the crown and the root system, and result in a retardation of both diameter and height growth. Height growth is the more important of the two during the early life period when pruning is initiated. It is essential that the pruned tree keep pace with its neighbors in height growth. Very soon diameter growth becomes of equal importance. Pruning of live limbs, without appreciably decreasing growth, can be extended up to the point where contact between the branches of adjoining trees ceases. All the living lower branches whose foliage does not receive direct light may be removed without decreasing the growth of the tree.

As an example of the effect of too severe live pruning on height growth, the figures in Table XVII, relating to an experiment conducted by the author in an eastern white pine plantation, are given. The pruning was done between the 1916 and the 1917 growing seasons.

TABLE XVII

FIGURES OF HEIGHT GROWTH TO SHOW EFFECTS OF PRUNING WHITE PINE

Treatment	Number of trees	Annual height growth in feet for the year 1915	1916	1917	1918
Pruned	112	1.87	2.13	1.45	1.43
Unpruned	169	1.53	1.75	1.95	2.13

The pruning was done in a plantation spaced 6 by 6 feet after its eighth growing season. The main stand ranged from 6 to 12 feet in height and had not completely closed. The branches clear to the base of the trees were still alive. All but the last three and in a few cases the last two whorls of live branches were removed, reducing the crown by more than 50 per cent. As a result of this too severe pruning the height growth of the pruned trees decreased approximately one third.

Other examples can be found in the literature showing reduction in diameter and in height growth after severe pruning. However, no example is known where following the above rule and cutting only limbs whose foliage does not receive direct light have resulted in reduction of growth. Undoubtedly with many species pruning can safely be carried farther up the stem. The measuring gauge would then be the percentage of total height to which pruning could go, or the percentage of live crown which could be removed without reduction of growth. Each species needs to be studied to determine what should be its limit of pruning severity. Craib (1939) states that in 4-year-old stands of *Pinus patula* pruning the branches up to 50 per cent of total height did not affect diameter or height growth, and pruning even up to 75 per cent of total height reduced growth for only 2 years after which the pruned stands again became equal to unpruned stands.

Bull (1943) investigated the effect of different degrees of pruning on the growth of open-grown longleaf pine. This species occurs very frequently in much understocked stands, and, if pruning is done at all, portions of the live crown directly exposed to light must be removed. Bull states that "open-grown longleaf pines at least 18 feet high should be pruned to 40 to 50 per cent of their total height, standards very easily checked in the field. Pruning to 40 per cent is a conservative practice that has no effect on growth. Pruning to 50 per cent usually removes about one-third of the live crown length, and will cause a slight loss in growth which should be outweighed by the better quality of the logs."

Selection of Trees and Time to Prune. Not all the trees in a stand should be pruned but only the relatively small number of the best, usually dominant individuals, which are expected to form the final crop, plus an allowance for casualties. Many things may happen to a tree before the end of a rotation, and so it is advisable in the beginning to prune as final-crop trees at least 20 per cent more trees than will be needed ultimately.

Only the final-crop trees should be pruned because the others will either die a natural death or be removed in intermediate cuttings. If pruned they would rarely, if ever, have time to develop a wide enough zone of clear lumber to repay the cost of pruning.

Better results are usually secured by selecting and marking the trees to be pruned ahead of the men doing the actual pruning work. This may be done by a special marker or by the foreman of the pruning crew as they advance. With well trained, competent workmen selection of trees can be left to them as they prune. This plan should be applied with caution, as making good selections is really quite difficult. The number of trees selected for pruning is likely to fall between 75 and 200 per acre.

Pruning should be started early in the life of the stand, while the branches to be cut are still small and the work consequently can be cheaply performed. If this is done the knotty core will be small and there will be time enough, even on a relatively short rotation, to develop around the knotty core a zone of wood free of knots, sufficiently wide to be manufactured separately from the knotty core. The importance of this last point should be emphasized. Justification for pruning individual trees depends upon whether the trees after pruning will be allowed to remain a long enough time to develop such a zone of clear wood.

The maximum diameter of the knotty core and the age of the tree when first pruned are of less importance than the time remaining after pruning before harvest. Although pruning of small trees has the advantage already stated of being cheap, pruning of larger trees is often justified, provided that the limbs removed are not so large as to encourage entrance of fungi and the tree will remain a satisfactory length of time. Oftentimes a larger tree, with consequently a bigger knotty core may be a wiser selection for pruning because of its vigor and stem quality than a smaller tree. There is little use in starting in the last half of a short rotation to prune trees already of merchantable size whose limbs are large and expensive to cut. The belt of clear wood subsequently added on such trees may not be thick enough to pay for the operation.

In managed forests the pruning should commence in youth, when the lower branches first start to die, and at intervals of a few years be continued on up the tree, until the desired length is freed of branches. This applies whether dead limbs only are cut or some live branches are cut in addition. Under this plan, it will require several (2 or 3) prunings to clear the trunk of branches for 17 feet above the ground, but, as 75 or more trees on an acre are pruned each time, the work can be economically conducted. Considering the saving in cutting small branches instead of large ones, the cost of several partial prunings should be less than one complete pruning.

Pruning becomes more expensive as it is carried higher up the tree, because either the trees have to be climbed, with or without ladders, or the pruning has to be done with tools mounted on long poles. In practice it is customary to prune high enough to produce clear lumber for the first 13 to 17 feet above the ground. A large proportion of the tree's volume will be contained in the butt log. If the financial returns made possible by pruning are large, it may pay to prune an additional log or two, but for the present the securing of a clear butt log usually is as far as the operation is likely to be extended.

If dead limbs only are pruned and living wood is not injured, the work may be performed during any convenient season of the year. In pruning live limbs it is best to conduct the operation when the tree is dormant. This is the period recommended for pruning in orchard management as giving the best results in non-injury to the stem, in subsequent wood growth, in healing of the wounds, and in freedom from infection by fungi.

Tools Employed in Forest Pruning. A wide variety of tools is available, and an equally wide range in opinion exists as to the best tools for the work. Before entering into a discussion of tools, it will be desirable to classify what may be termed for our purpose the methods of accomplishing the pruning. These methods are:

1. Climbing the bole of the tree and pruning from this position. (Branches within easy reach of a man with hand tool standing on ground are cut from the ground.)
   (*a*) Climbing with the aid of climbing irons and pruning progressively upward.
   (*b*) Climbing up on the branches and pruning progressively downward (Tarzan method).
   (*c*) Climbing on a ladder and pruning progressively upward.
2. Standing on the ground and pruning to desired height with tools mounted upon poles.

In both methods branches within easy reach are cut off with a hand tool by the operator while standing on the ground. Obviously the method of accomplishing the pruning will influence the selection of tools.

Requirements of good pruning, irrespective of the tool used, are that the cuts should be: close to the tree trunk and flush with it, leaving no splinters of wood; and made without tearing or loosening the bark around the branch stub and without wounding the stem of the tree.

A pruning tool will be judged on the basis of its ability to satisfy the requirements of good pruning, with a minimum expenditure of time and energy and with safety to the operator. Since pruning will need to be done under combinations of many different conditions, it is illogical to expect any one tool to be always the best. The purpose in this discussion is to bring out the good and bad points peculiar to each of the important pruning tools. A careful study of local conditions is essential for making a wise choice of tools for pruning.

Among the factors which have important bearing on selection of pruning tools are the following:

Species to be pruned. The maximum size of the limb removed, the angle at which the branch leaves stem, the number of limbs per whorl, the thickness of the bark, and other details vary with species and will affect pruning.

Class of branch. There is a difference in the same species between pruning dead and live limbs and between pruning large and small branches.

Distance above ground to which pruning will be done. Some tools are best suited for use only at certain heights above ground; others are effective at all heights.

Topography and underbrush. These are minor factors but they influence relative effectiveness of pruning tools.

Labor available. The type of men that can be secured will influence choice of tools and of method for accomplishing the pruning. An old, heavy, clumsy man should not be set to work climbing trees or equipped with an axe, whereas he may work less badly with a pole saw.

Tools may be classified into:

Saws; hand, pole, power.

Edge tools cutting by impact; axes, billhooks (brushhooks), chisels, and pullers.

Two-handed pruning shears.

Clubs.

Saws. A great variety of hand saws is on the market. Practically all forest pruners are agreed that the best hand saw is the small curved type commonly used in horticultural work. It has a pistol grip and a blade 12 to 16 inches long, tapering in width from about 2 inches to about ½ inch at the end. The blade must, however, be rigid. The teeth should number 5 to 8 to the inch and be long and acute. The blade should be designed to cut on both the push and pull strokes (principally the latter). As a saw of this type, Disston No. 53 is preferred by the author for pruning eastern white pine.

The hand saw is the easiest and safest pruning tool. It is fast and effective on branches of all sizes. All saws leave a rough surface as compared to impact cutting tools and shears. This feature is of no practical importance, since healing over progresses satisfactorily on sawn stubs.

The hand saw, if used above the reach of a man standing on the ground, must be operated by a climber, either standing on a ladder or clinging to the stem of the tree.

When so used, the hand saw comes into direct competition with the pole saw. Among the various pole saws in use, the one generally approved has a slightly concave, narrow, stiff blade about 18 inches long with 5 teeth to the inch. It cuts on the draw stroke. The saw can be mounted on a pole of any desired length. Since it is awkward to prune branches relatively near the ground with a long pole, poles of two or more different lengths are used in pruning, from 7 or 8 feet up to 17 to 25 feet. Branches within a man's reach are pruned with a hand saw. As the height above ground increases, the difficulty and fatigue of accurately operating a pole saw increases. For doing good work the saw blade must be stiff and the pole rigid. The pole saw requires more concentration and effort on the part of the operator to make the cuts close to the trunk than the hand saw. Since the operator must be looking upward while pruning and must handle a long pole as well as a saw, the fatigue is greater than in using a hand saw. Falling sawdust may get into operator's eyes, which should be protected by goggles or perhaps by a peaked cap.

Where limbs are small, the pole saw is undoubtedly faster than the hand saw used from a ladder, since more time is lost in moving the ladder than in shifting the pole saw around the tree. As the branches get larger with increasing height above ground and the pole must be lengthened, the hand saw used from a ladder may take less time than a pole saw. This is likely to be true of plantation pruning of such trees as eastern white pine. For pruning higher than 7 feet above ground, climbing and pruning by the Tarzan method with the

hand saw is cheaper than pruning from a ladder with this tool. However, the Tarzan method is effective only when employed by young, active men of relatively light weight, in trees so large that the stems will not bend over or break with their weight, and with limbs strong enough to support the men.

An objection to ladders, sometimes cited, is that they cannot be used in pruning small trees. It is doubtful that trees ready for pruning will be so slender and lacking in rigidity as to preclude the use of a ladder. Ladders for forest pruning should be specially constructed for the purpose. The best type is light, narrows toward the top, and has a curved top rung (concave toward the tree trunk). This special rung may be a curved piece of metal wrapped with cloth to protect the tree from wounding or a short cable or a rubber hose enclosing strong wires which conforms to the shape of the tree trunk against which it rests.

Jacobs (1938) suggests that the ladder be equipped with a platform step near the top, and that the ladder be shifted around the tree by the operator raising himself by grasping branches above his head, hooking his toes under the platform step and swinging the ladder around into a new position against the tree. This would avoid the time-consuming feature in ladder pruning of descending and shifting the ladder around the tree. Such action is not often necessary as the pruner can frequently saw off the limbs completely around the tree from one ladder placement.

In saw-pruning a different length of ladder or pruning pole is needed for each pruning zone of approximately 5 feet in height, after the ground pruning zone of 7 feet is finished without the aid of ladder or pole.

Hawley and Clapp (1935) developed a method of pruning eastern white pine plantations in three operations: the first a low pruning up to 7 feet done by means of a curved hand saw with the operator standing on the ground; the second a high pruning from 7 to 12 feet above the ground, the operator using the same saw from an 8-foot ladder; and the third a high pruning from 12 to 17 feet above the ground, the operator using a 12-foot ladder and the same saw.

Under the conditions prevailing in these plantations, the saw-and-ladder method proved to be cheaper and better than the pole-saw method using 8- and 12-foot handles. It is believed that where many of the limbs to be cut are alive and 1 to 2 inches in diameter, the ladder method will be found superior, unless surface conditions hinder the moving of the ladder. This system is often modified to the extent

of delaying the first pruning until the trees are 18 to 20 feet high and then pruning up to 12 feet in one operation.

Moss (1937) compared pole-saw with ladder-and-hand-saw pruning for hardwoods and concluded that the actual sawing time was the same on the two methods. Since the pole saw could be shifted around the tree more quickly than the ladder, the total time for pruning was less with a pole saw. The pole saw, however, proved more fatiguing, and as branches increased in size the ladder method was preferred.

Mollenhauer (1938) considers a pole saw to be the best pruning tool on eastern white pine between heights of 7 to 14 feet, although it is tiring on the operators. Above 15 feet he prefers the Tarzan method.

One of the best summaries of the comparative merits of pole-saw and hand-saw-ladder pruning is found in the following quotation from Bull (1937), who at the time was studying pruning of longleaf pine:

"The quality of the work done by the better pole saw was fully as good as that done by the best hand saws. At first, none of the men liked the pole saw because it was very tiring and awkward to use. Soon, however, they acquired the knack of using it, and then most of the men preferred it to the hand-saw-and-ladder method. If not used too steadily by one man, the pole saw is not unduly fatiguing. Usually the work can be so arranged that a man is not required to use a pole saw exclusively for long periods. Some men, however, even after much practice, apparently are unable to use a pole saw skillfully. These men usually do much better with a hand saw and ladder.

"A final but very important consideration in comparing the two methods is the size of the trees. Unless the tree is at least 5 inches d.b.h., pruning from a ladder is difficult, dangerous, and usually impossible. For trees about 8 inches or larger d.b.h. and especially trees with large limbs, the ladder method is likely to be not only somewhat faster but its results are better. For trees between 5 and 8 inches, either method is satisfactory. Whichever better suits the workmen, may be considered the more efficient method. Judged by these tests, a good man with a pole saw can prune medium-sized trees somewhat faster than an equally good man with a hand saw and ladder; but it is probably somewhat easier to find a good man for the latter method than for the pole saw.

"The preceding paragraphs apply only to pruning up to 17 feet."

Ultimately a power saw especially adapted to forest pruning is likely to be developed; it should reduce pruning costs in places where labor is expensive. Cuno (1935), who has carried on studies in this

field, indicates that such equipment is practical. The saw would be mounted on a pole. The chief problem is to develop a source of power easily portable in the forest.

Edge Tools Cutting by Impact. Among such tools the axe has been frequently employed. The consensus of opinion is that the axe is a pruning tool suitable only for skillful axemen. Even in their hands severe wounds are inflicted upon the pruned trees. The axe and other cutting tools make smooth, clean cuts, but an exceptionally high degree of skill is required to make such cuts as close to the tree as the average saw cut and avoid wounding the tree. The advantage, often claimed for axes and similar tools, that the clean, smooth cuts heal over better than those made by saws is incorrect. Jacobs (1938) states that cuts with axe, pruning shears, or saw all heal over equally well, provided that there is no injury to surrounding cambium. Occlusion over branch stubs progresses rapidly over the slightly roughened surfaces left by saw cuts.

In pruning with an impact cutting tool the blows should be made upward or from the side rather than downward, to avoid tearing the bark and wood.

Brushhooks and billhooks for forest pruning also have their advocates. What is said regarding axes applies to these tools as well.

A third type of impact cutting tool may be termed a chisel and puller. The Rich pruning tool (Rich 1935) is an example of this type, designed for use in naturally reproduced stands of eastern white pine. It can be used both as a chisel with an upward thrusting motion and as a puller brought down from above upon the branch. Tools of this type require skill to get close cuts and too much physical power for the average man to use effectively. Where all the limbs to be pruned are dead and very small, such tools work very well.

Photographs of quite an assortment of pruning irons (chisels and pullers) used in Sweden are shown by Carlgren *et al.* (1937). However, he considers pruning irons less effective than saws, with usefulness principally for limbs dead up to pruning height and in a pruning zone of intermediate height. Williamson (1939), discussing plantation pruning in New Zealand, advocates a "lance chisel" mounted on a pole with an iron ring on the lower end. This tool is operated by two men, one holding the chisel against the limb while the other swings a wooden maul with an upward stroke against the lower end of the pole.

Pruning Shears. The type of pruning shears suitable for forest pruning is the two-hand shear that is 20 to 36 inches in length. The

type operated in one hand, so widely used in horticulture, does not have the capacity to cut branches of the size encountered in forest pruning.

The author knows of only one make of pruning shears available in this country which can be classed as an effective forest-pruning tool. This has two opposing blades cutting by pressure rather than by impact. Most two-handed pruning shears have one dull blade opposed to a cutting edge with the result that a protruding stub is left and the base of the branch is squeezed and bruised. With pruning shears having two opposing cutting blades as close cuts can be made as with saws. To do so requires more skill and concentration on the part of the operator than is required in operating a hand saw. In speed the shears are usually rated a little faster than the saw (Davis 1936). To obtain equally good work may require as much time as with the saw. Since the shears require continuous use of both hands, and the weight of the tool (which is appreciable) is at the end farthest from the operator, fatigue is greater than with the hand saw. Shears can be used only for branches up to a certain size which is below the maximum normally met in most forest pruning, whereas saws are effective on branches of all sizes.

Shears are best suited for pruning the zone from ground up to 7 or 8 feet where branches are less than an inch in diameter. Above this point the necessity of having both hands operating the tool is a disadvantage.

Clubs. Forest pruning may be accomplished by knocking off the limbs with a club. This relatively crude practice has often been employed in knocking off the dead lower limbs from all trees in dense stands of young conifers, to afford space for walking through the stand and selecting individual trees for higher pruning.

Within recent years a special type of club, known as the Hebo pruning club (Kachin 1940 and Zach 1941), has been developed for forest pruning. It consists of a handle shod with a piece of steel and is made in two sizes. The larger is 33 inches long with an 8-inch steel ferrule and is intended to be swung with both hands. A smaller tool 17 to 19 inches long with a 5-inch ferrule is swung in one hand. The clubs can be used from the ground, from ladders, or in the trees. In second-growth stands of Douglas-fir, the trees are climbed by a man, equipped with multiple-spur climbing irons, who knocks off the branches with the small club.

The Hebo pruning club is much faster than the hand saw, particularly for pruning high above the ground by a climber. Costs of either hand-saw pruning from ladders or pole-saw pruning increase

rapidly with distance above ground. A tree climber can prune high up the tree as cheaply as at medium heights. With the long-handled Hebo club limbs can be pruned from the ground up to a height of 10 or 12 feet.

Another advantage is inherent to club pruning, namely closer pruning than is possible in other methods. Branches knocked off with the Hebo club break inside the limb collar and, instead of leaving short stubs out over which the callus must grow, actually leave holes or depressions within the pruned tree trunk. Callus rolls into these depressions and covers the wound more quickly than the usual branch stub.

The method has been tried out principally on Douglas-fir. Whether a similar class of breaks can be secured on other species remains to be seen. To break in this way, in Douglas-fir or any other species, the branches must be dead, dry, and brittle. The method is less effective on live limbs.

A strong objection to the method is that, like the axe, a pruning club requires skill to use and in the hands of an unskillful person will cause severe bruising and wounding to the tree trunk and branch collar. Apparently Douglas-fir bark is sufficiently thick so that bruises to the stem are unimportant, as are the wounds caused by multiple spurs which penetrate only ½ inch.

Cost of Pruning. Pruning requires a present expenditure for the purpose of increasing the unit value of the final product. The probable returns to be expected should be estimated and compared with the expenditures necessary to obtain them, before decision is made as to the advisability of pruning in any specific stand. The cost of pruning a 17-foot length is likely to lie between 3 and 12 cents per tree. In eastern white pine between 75 and 125 linear feet of bole can be pruned per man-hour. Hawley and Clapp (1935) found the initial cost of pruning plantations of this species to be 11 cents per tree, which, compounded to the end of a 60-year rotation, amounted to approximately 42 cents per tree at 3 per cent interest, and 64 cents at 4 per cent. The latter figure represents a cost of about $3.56 per thousand feet, board measure, for lumber produced in the pruned portion of the tree. The profit from the operation was estimated to be about $15 per thousand feet, board measure.

Paul (1931) states that if stands of old-field loblolly pine had been pruned early in life, when about 15 years old, the value of the lumber produced could have been increased by approximately $100 per acre. He estimates that expenditures of $9 to $23 per acre for pruning would have paid 6 per cent compound interest.

Although what has been said so far would seem to indicate that forest pruning will be generally applicable, it should by no means be taken for granted without careful investigation in specific stands. Financial success in pruning depends upon production of an adequate zone of clear wood, and this in turn depends upon the growth rate of the pruned trees and the length of time they will be left to grow.

Mattoon (1942) considered the pruning of all four of the southern pines, shortleaf, loblolly, slash, and longleaf, to be a profitable operation. With the last two of these species pruning would have the purpose not only of producing clear grades of lumber but also of providing knot-free faces for chipping for turpentine.

Cline and Fletcher (1928) estimate the profit from pruning white pine at $15 to $35 per thousand feet, board measure. They also suggest that white pine should not be pruned unless the work can be done at the rate of at least 75 linear feet of bole pruned per man-hour.

The advisability of any pruning investment is contingent upon producing given sizes within a stipulated time. The thinning schedule must be closely linked with the pruning policy. Ordinarily heavy thinnings will be needed to make a financial success of pruning. Conversely, artificial pruning will make possible heavier thinnings than would be justified if reliance were placed only on natural pruning. If artificial pruning will be employed, spacings in forest plantations can be wider, thereby effecting substantial savings in costs of establishment.

The fact must not be overlooked that heavy thinning and artificial pruning while producing butt logs of large diameter, fast growth, and clear lumber will also produce top logs with relatively large knots and no clear lumber. Where slow growth is essential to produce the quality of wood wanted, and consequently only light thinnings or none at all will be made, artificial pruning may be inadvisable. The investment in pruning is ordinarily too high to be regained without maintaining a fast rate of diameter growth on pruned trees.

Knowledge of the space which will be occupied at the end of the rotation by pruned trees carried forward at a fast growth rate by systematic heavy thinnings is essential for accurate determination of the number of trees per acre to be pruned. Costs may be tremendously increased by pruning more trees than can be carried to the end of the rotation.

The relatively small amount of information as yet available indicates that for plantations of eastern white pine, in the northeastern United States on the better half of the planting sites, the pruning of

75 carefully selected trees should be ample to occupy the area fully, with pruned trees only, at the end of a 60-year rotation. This premise assumes systematic thinnings from the twenty-fifth year on to favor the pruned trees. The final crop, per acre, is expected to consist of 45 to 60 trees, 18 to 24 inches in diameter, containing a volume of 25,000 to 30,000 feet, board measure. Pruning of these trees to 30 feet above ground is likely to prove profitable.

Craib (1939) furnishes an excellent illustration of the close relationship which should exist among spacing of plantations, thinning schedule, pruning schedule, and rotation age, in his study of yellow pine plantations in South Africa. For example he demonstrates that, for one species, *Pinus insignis*, on Site I, 150 trees per acre should be pruned to 10 feet at 6 years, 16 feet at 8 years, and 22 feet at 9 years, and harvested on a rotation of 30 years. The first pruning comes at the time of the first thinning, and subsequent thinnings must be made as scheduled, if the minimum 4-inch zone of clear wood is to be obtained in the butt logs. On Site II the growth rate justifies pruning 200 trees but only to 10 feet, while on Site III pruning cannot be justified.

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CHAPTER XIV

METHODS OF CONTROLLING CUTTINGS

In silvicultural operations, including both reproduction and intermediate cuttings, rarely are all the trees on any large area removed at one time.

The felling and removal of the trees ordinarily falls into the hands of a lumberman who may have bought the timber or contracted to log it. His interests lie in logging the timber as cheaply as possible without paying much attention to preserving the trees (from those in the reproduction stage up to mature timber) that are to be left on the area. Under the circumstances, it is essential that the forester devise means to control the work of the operator to the extent of preventing the cutting or destruction of trees that should remain.

Two methods are available: control through inspection alone and control through marking of the trees (which also involves inspection).

From the silvicultural standpoint it would be better to have the forester carry on the operations of felling and removing the forest products. The practice, largely prevalent today, of placing the removal of the timber in the hands of purchasers or contractors, whose primary interest is cheap logging, cannot be considered ideal. Ultimately the man who has charge of growing the timber should have direct control of the work of harvesting.

All operations connected with the removal from the forest of wood and timber, at least up to the point when the products are delivered to the side of the forest roads, can to silvicultural advantage be conducted by the forest officers. The benefits to the forest accruing from such procedure are well recognized, and the method is widely applied abroad but unhappily not in the United States. On some small tracts the method is in use. Occasionally on a large holding the essence of the idea is applied. Companies owning lands and mills or wood-using plants and having forestry departments would appear to be exceptionally well situated for securing excellent silvicultural results. Unfortunately it often happens that the forestry department and the logging department are divorced and have different goals; the one, continuous production of forest crops, the other, cheap logs. This situation is changing just as fast as foresters gain control of the

operating end of forest-land management. Eventually the control of the logging operations will come directly under the forester on private as well as on public lands. Even when production and harvest of the timber are thus closely brought into harmony under one control, it will still be necessary for the forester to exercise his control of cutting operations by inspection, by marking the trees, or by both.

Control through Inspection. Definite instructions as to the type of cutting desired can be given to the man in charge of logging the area, and his work can be controlled by inspection of the operations. Control by inspection has the advantage of leaving more responsibility with the operator, who may be sensitive to having his authority curtailed. If the men in charge of the logging are in sympathy with the silvicultural viewpoint, good results may be secured by this method. Otherwise it will be difficult to accomplish even the minimum silvicultural requirements. Much depends on the frequency and carefulness of the inspections, particularly during the first season.

The method has less to recommend it than control through marking of the trees. It is useful either in the initial stage when silviculture is being introduced to replace forest exploitation or later when a trained personnel is available, capable of applying the simpler silvicultural operations according to verbal instructions.

Control through Marking of the Trees. This is accomplished by designating either the individual trees to be cut or those to be left. The operator is responsible only for the work of removing the designated trees with due care for those left standing, their selection falling under the province of the silviculturist. Marking the tree as a method of control is far superior to inspection because it substitutes an exact designation by individual trees for verbal instructions. It should be employed wherever there is any doubt about securing satisfactory results through control by inspection. The tendency is toward a more widespread use of marking.

The necessity for care to avoid unnecessary damage to standing trees on the part of the logger still exists even though marking is carried on. In fact his attitude must be one of sympathetic cooperation with the silvicultural policy if the best results are to be attained. Where marking is done less opportunity is allowed him for seriously interfering with the style of cutting. As operators gain experience in making cuttings in the practice of silviculture, they probably will prefer the method of marking rather than control by inspection alone, because the marking method relieves them of considerable responsibility and allows their attention to be centered upon the logging end of the work.

Inspection is necessary under the marking method to see that the cutting is properly executed, but the whole success of the cutting does not so vitally depend upon frequent and close inspection as under the first method.

Either the trees to be cut or those to remain may be marked. The relative number of trees to be cut, or left, is instrumental in determining which of the two classes should be marked. When the trees to cut are relatively few, it is cheaper to mark the trees to come out; when they are many, the trees to remain are marked. Where an area is to be cut clear, simply marking the boundaries of the area so treated is sufficient.

If the trees to be cut are marked, a blaze going through the bark into the wood is often the designation used. The blaze is made on the trunk at a convenient height above ground, approximately breast high, so as to be readily seen, or else is placed on a root swelling or on the trunk so low as to appear on the side of the cut stump. The advantage of having the blaze placed on the stump is that it serves as an excellent check upon the operator's work.

Two blazes may be placed on the tree, one where it can be readily seen and the other on the stump. A plain blaze is of little use as a check on the operator because it may be difficult to determine by whom such a blaze was made. For this reason it is customary to stamp a letter or symbol on the blaze. This should be done on the stump blaze in any case and sometimes also on the higher blaze.

If desired, the two blazes can be used to control the direction in which the tree should be felled and the height of stump that should be cut. For example, the upper blaze instead of being breast high might be placed just above the desired saw cut, and as the blaze must appear on the butt log after cutting, a low stump will have to be cut. The position of the lower blaze may indicate either that the undercut is to be placed on the opposite side of the tree or that the tree should be felled toward the blazed side.

Axes have been employed frequently as the marking tools in this country. Where the blazes are to be stamped, a special marking axe may be used with the desired letter or symbol placed on the head. Timber scribes are often used in marking trees which do not have thick, tough bark, provided that no stamping of the blazes is necessary. Dengler (1941) describes a tree marker consisting of a short axe handle and a curved cutting edge, which he considers faster than an axe or hatchet.

Red lead and various other powdered materials, applied with specially designed swatters or with brushes, are sometimes used in

marking, as is crayon. Paint or whitewash is sometimes applied with a brush. The fastest method of designating trees to be cut is to squirt paint upon them by means of a hand spray gun. The operator does not have to go to every tree, being able to squirt paint for at least 5 to 15 feet (Folsom 1937, Rulison 1942), thus saving time and distance in covering the territory. Also, to spray a tree with paint requires less time than to cut and stamp two blazes. Altogether from 10 to 50 per cent in time is saved in using a spray gun instead of blazing with an axe. Where the number of trees to be marked at one time and place is small, the axe may still prove to be the more satisfactory tool, because of the bother incident upon preparing and handling paint and cleaning the gun.

To use the gun efficiently the operator must be equipped to clean it each day and must expect to get some paint on his clothes. The paint selected must be of a color that shows clearly against the bark of the trees and does not fade. Red, orange, yellow, and light blue have proved successful with different species of tree.

As a check on the cutting, paint is less effective than stamped blazes because it is more easily counterfeited.

Bratton and Ferguson (1945) have brought up to date and summarized information in regard to the advantages, disadvantages, and details of using the spray gun. Their article should be consulted by foresters who plan to use the spray gun in marking timber.

It is not advisable to mark trees that are to be retained with blazes extending through the bark into the wood, on account of the possibility of insects or fungi obtaining access to the tree through the wounds. Hence paint should be employed when it is desired to designate the trees that are to remain. Sometimes a spot of paint is sprayed on the trunk and stump or a ring is painted around the tree.

Marking when done on reasonably large scale is not an expensive operation, costing usually between 3 and 15 cents per thousand feet, board measure, including the necessary inspection after the cutting. If the total amount marked on a given sale area is very small, particularly if the area is inaccessible or measurements are taken of the marked trees, the cost of marking will be much higher. The cost is figured per thousand feet, board measure, of timber cut, and depends primarily upon the size of the timber, the amount cut per acre, the topographic and surface conditions of the area, the density of the underbrush and young growth, and the time required for travel to and from the job. A stand containing individual trees of large size, in which a heavy cutting is made, on level land free from

underbrush, reproduction, rocks, or other obstructions, will cost less per thousand feet cut than when these conditions are reversed.

The system of marking suggested for use in connection with each of the various kinds of reproduction and intermediate cutting is indicated in Table XVIII.

TABLE XVIII

MARKING SYSTEMS FOR VARIOUS CUTTING METHODS

Kind of Cutting	System of Marking
Reproduction cuttings	
Clearcutting	Mark the boundaries of the area to be cut clear.
Seed tree	Mark the seed trees which are to remain in such a manner as not to cause wounds. A ring of paint around the trunk is excellent for this purpose. Marking the seed trees will cost less than marking all the trees to be cut.
Shelterwood	
Preparatory, seed, and removal cuttings	Mark all trees to be cut.
Final cutting	Mark the boundaries of the area on which the final cutting is to be made or mark all trees to be cut.
Selection	Mark all trees to be cut.
Coppice	Mark the boundaries of the area to be cut clear.
Coppice with standards	Mark with rings of paint the young standards to be retained when the coppice is cut. Mark all trees to be removed among the other standard classes.
Intermediate cuttings	
Cleanings	Let the selection of the vines, shrubs, and trees to be removed be done by the choppers as the operation proceeds. Supervise closely unless the work is done by men skilled in the operation.
Liberation cuttings	Mark the trees to come out, or leave their selection to the choppers as the work proceeds.
Thinnings	Mark the trees to come out or those to be left; in very young stands use spacing standards.
Improvement cuttings	Mark the trees to come out.
Salvage cuttings	Mark the trees to come out. Where trees to be removed are entirely dead or severely injured they can be selected by the choppers as the work proceeds.
Pruning	Mark, in such a manner as not to cause wounds, the trees to be pruned.

Good marking is a primary factor in obtaining satisfactory results in growth and often has an important influence on reproduction on cutting areas. The operation appears simple, but in reality it de-

mands a high degree of skill on the part of the marker. To be a competent marker, the forester must possess a thorough understanding of the local economic conditions and logging practice and ample knowledge of the silvicultural habits and requirements of the species in the stand and the silvicultural policy in force, enabling him to decide quickly and accurately (almost intuitively) the fate of each tree. It is evident that the requirements call for local experience. Indeed ability to mark well is distinctly a local achievement.

To become an expert marker requires years of experience. The forester should take advantage of every opportunity for enlarging his ability to mark timber.

Simmons (1944) recommends, for training inexperienced men in marking timber, the use of demonstration and test plots upon which each tree is numbered and described and reasons are given for its being marked or left. On the demonstration half of the plot this information is available to the trainee; on the test half of the plot he gains experience in marking and then checks his selections against the data.

Marking Rules. Since successful marking is so firmly grounded on a knowledge of local conditions, natural and economic, it may appear to be one of the points in silvicultural practice which is least susceptible of standardization. Yet it is true also that, for each forest type within any region having reasonably uniform natural and economic conditions or for the region itself, certain generalizations as to the proper marking practice can be made. These generalizations will be most helpful in orienting the young practitioner who is beginning to develop local experience. Eventually a ripened knowledge enables the necessary local modifications to be sensed and turns a stereotyped mechanical marking into an expert application of silviculture accurately fitted to the needs of each stand.

The usefulness, in the present stage of our silvicultural development, of generalized statements of marking practice has led to the development of what may be termed "marking rules." Marking rules in their simplest form comprise a set of instructions for marking timber. To be of practical use they must refer specifically to a single species, forest type, or region and usually to a given forest area.

It is logical that any organization, public or private, with a large and continually shifting personnel and with extensive areas of forest under management should find marking rules valuable in standardizing practice between individuals and between various areas of the same forest type. In opposition to this viewpoint the argument has been advanced that the employment of marking rules so standardize

practice and make marking so routine and machine-like as to kill initiative and development of technical skill on the part of the forest officer, and thus produce bad examples of silvicultural practice. As in all other matters of silvicultural practice, if marking rules are applied rigidly the effects on the foresters and on the forest may be bad. The extent to which this statement is true depends primarily upon the intelligence of the personnel and the accuracy of the rules themselves. With a personnel relatively ignorant of silviculture and with a well thought out set of marking rules, routine or mechanical application may easily secure better results in the woods than free play for the judgment of the individual marker.

It is wiser for marking rules to be viewed not as rigid regulations but as guiding principles subject to modifications to fit the local conditions. As the intelligence of the personnel increases, and particularly if it becomes possible to retain the same forest officer for a reasonably long period on a given forest area, the local adaptations will come to overshadow and finally supersede the general marking rules. Eventually very specific instruction for marking on each silvicultural unit can be developed. Today in most places silviculture has not been practiced long enough to furnish the basis of knowledge for such local instructions. Indeed the general marking rules for the species or the forest type usually rest on none too secure a grounding of knowledge.

Marking rules have been used principally by the United States Forest Service in their publications concerning various commercial trees and in the application of silviculture in the National Forests. Such rules may range from simple instructions as to the classes of trees to be marked, up to statements summarizing the important silvicultural characteristics of the species and outlining the methods of reproduction and treatment throughout the rotation to be used for the given tree or type.

Marking rules are intended primarily for the assistance of the forest officers in charge of the marking on timber sales. If only one kind of cutting, such as a grade-*C* thinning or a clearcutting for reproduction, is required uniformly over the area very brief instructions will suffice. This is not the situation that prevails in our unmanaged or previously mismanaged forests, on the National Forest sale areas or elsewhere, except in small stands. Usually on the area to be operated at one time there will be several stands, or at least a great diversity of conditions within the one stand, which make necessary a variety of different cuttings all combined in a single operation. To mark such a stand intelligently requires information about all phases

of the silvicultural plan of management for the tree and type concerned, including accurate knowledge of the products for which different classes of trees can be utilized.

Marking rules when most highly developed supply the necessary information in concise form and are in fact summarized plans of silvicultural management. It is desirable that such marking rules or silvicultural plans be drawn up for all species or forest types of commercial importance.

Tree Classifications. Tree classifications for specified forest types or species have proved of assistance in drawing up a set of marking rules, in studying the results of applying such rules for marking timber, or in facilitating their consistent application.

In fact such a classification, whether formally expressed or not, is the basis of all marking practice. The chief factors involved, as far as the trees themselves are concerned, in determining whether individuals should be cut or left are age, merchantability, potential growth capacity both quantitative and qualititative, and health. Age is of importance primarily as a significant influence in affecting the other three factors.

Tree classifications find their greatest usefulness where old timber is being harvested in reproduction cuttings in forests of unevenaged or irregular form, particularly where the age classes are in intimate mixture.

Dunning (1928) led the way in developing a tree classification of this nature intended primarily for the selection forests of the Sierra Nevada and particularly for ponderosa pine. He classified trees into seven tree classes distinguished first on age (four classes), second on degree of dominance inside each age group (five crown classes), third on crown development (covered by description), and fourth on thrift (designated in three degrees of vigor). To present the classification more clearly, the arrangement in Table XIX has been made of the first, second, and fourth factors, with a column added to show the cutting recommendation for each class.

It will be seen that the cutting is made principally in the oldest timber and that, where merchantable, the intermediate and overtopped trees also are removed, unless in young and thrifty mature age classes these lower-class trees will be released from competition by the removal of other trees.

Dunning's classification proved so useful in regulating marking practice in the Sierras that other men were stimulated to develop similar classifications for other species and conditions. Keen (1936) developed another tree classification for ponderosa pine in the Pacific

TABLE XIX

Tree Class	Crown Class	Age Class*	Vigor	Recommendation for Marking
1	Isolated, dominant, rarely codominant	Young and thrifty mature	Good	Leave when sound
2	Codominant, rarely isolated or dominant	Young and thrifty mature	Good to moderate	Usually leave but cut some
3	Isolated, dominant, rarely codominant	Mature	Moderate	Cut part and leave part
4	Codominant, rarely isolated or dominant	Mature	Moderate to poor	Cut unless no other available seed trees
5	Isolated, dominant, rarely codominant	Overmature	Poor	Cut unless no other available seed trees
6	Intermediate, overtopped	Young and thrifty mature	Moderate to poor	Cut, if merchantable, unless freed from competition
7	Intermediate, overtopped	Mature and overmature	Poor	Cut if merchantable

* *Young* — less than 50 years. *Thrifty mature* — 50 to 150 years. *Mature* — 150 to 300 years. *Overmature* — over 300 years.

region, mainly from the standpoint of bark-beetle susceptibility. It is so well conceived and so thoroughly expressive of the life cycle of ponderosa pine that it has proved useful in selecting trees in cutting operations, even where bark-beetle susceptibility is not the main factor in selection. The classification is based on the two major factors of age and crown vigor. Four age classes are recognized with 4 vigor classes within each age class, making a total of 16 classes. Later new definitions based on additional data (Keen 1943) were issued. The 4 age classes are termed 1 — young, 2 — immature, 3 — mature, and 4 — overmature and should be thought of as grouped by relative maturity rather than by any definite age limit. Actual age limits for the groups will vary in different parts of the ponderosa pine region. Keen states that color and type of bark, total height, shape of top, character of branches and branching, and diameter are the chief external indications of maturity, which must be locally ascertained. The four crown vigor classes are described as A — full vigor, B — good to fair vigor, C — fair to poor vigor, and D — very poor vigor. The size of crown (length, width, and circumference), its density, and the form of the top were found to be the chief factors (for the same site and age class) influencing the crown vigor and consequently its inherent growth capacity. Keen's tree classification showing the form of tree characteristic of each age and vigor class is given in Figure 69. Significant differences in growth rate have been found between trees of the different age and vigor classes. This as well as varying susceptibility to bark-beetle attack justifies their recognition as a basis for marking.

Salman and Bongberg (1942) found that, although Keen's classi-

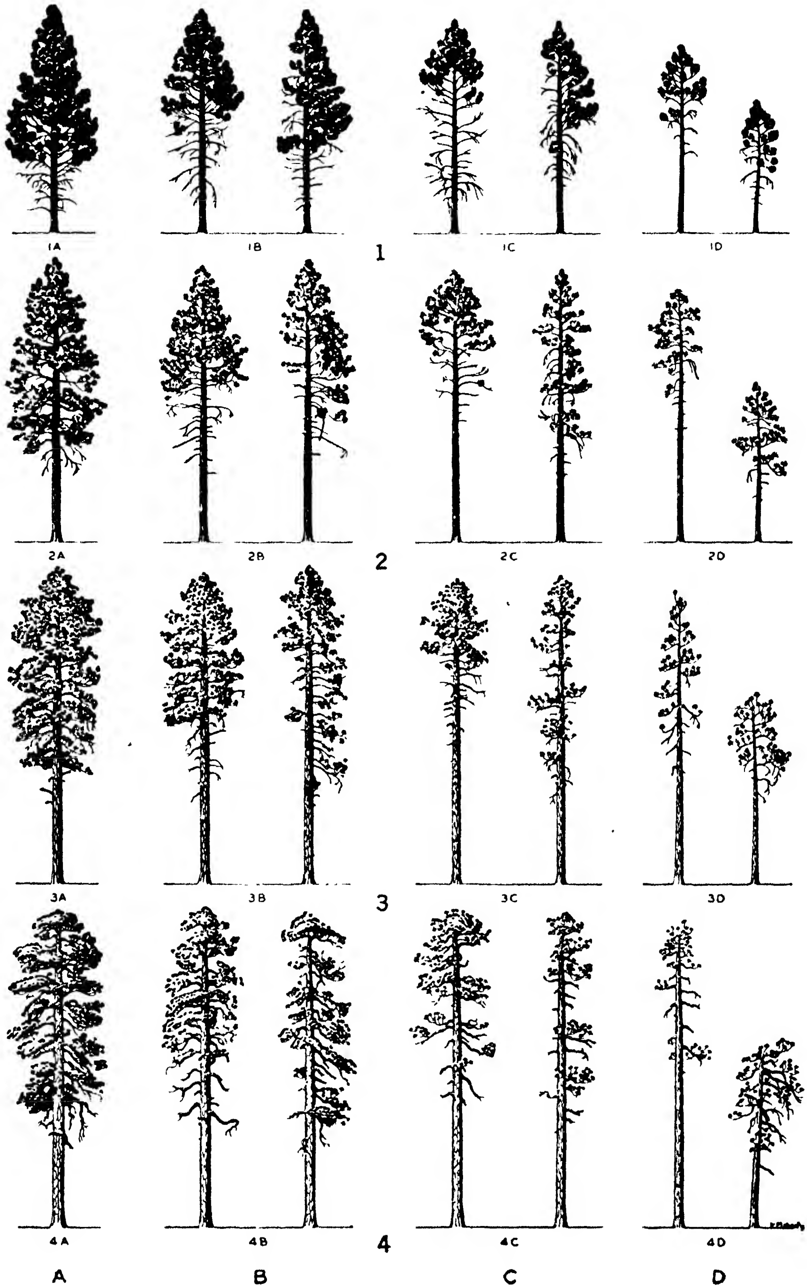

Fig. 69.

Keen's ponderosa pine tree classification based on four age classes from 1, the youngest, to 4, the oldest, and on four vigor classes from *A*, the most vigorous, to *D*, the poorest.

fication indicated in general terms the susceptibility of the trees to bark-beetle attack, yet the distinctions possible by the use of these classes were not finely enough drawn to identify accurately the trees which would be killed by beetles first. Such information was considered necessary to mark for the light cutting desirable for bark-beetle control. As a basis for marking such a cutting, a system of risk ratings by 4 risk classes was developed taking the condition of the foliage as the means of separation into risk classes. The number of needles per twig, the length of the needles, color of the needles, the vigor of twigs and branches, and the extent of insect infestations were the principal factors made use of in the rating.

Evidently Keen and Salman (1942) consider the risk ratings preferable for assistance in marking light cuttings on a short cutting cycle in which only the most susceptible trees should be removed, and they would use Keen's tree classification for controlling marking where longer intervals will elapse between cuttings.

Hornibrook (1939), working with ponderosa pine in the Black Hills, investigated the reliability of Keen's classification as a criterion of the relative growth capacities of trees, both in uncut stands and in those selectively logged 25 years before. He concluded that, if the tree-class descriptions were modified to fit Black Hills conditions, Keen's classification was an excellent criterion of relative growth capacity, in both uncut and cut stands, and would furnish a basis for marking rules. Thomson (1940) modified Keen's classification in the ponderosa pine type in the Southwest and found it a good basis for marking.

A further refinement in marking ponderosa pine in the Pacific region (Brandstrom 1940) is the appraisal of the money value in each tree and its selection for cutting or retention on this basis, considered in combination with its relative growth capacity as indicated by the Keen tree classification.

What has been said of ponderosa pine concerning the development of tree classifications and the consequent possibility of closely appraising each tree's relative value for retention or cutting will serve to illustrate the detailed consideration which can be given to the selection of trees in marking timber. More has been done along the line of tree classifications in ponderosa pine stands than in any other forest type.

These same ideas can be applied to other species and regions, and a few beginnings have already been made. Heiberg (1942) has prepared tables of tree values for marking eastern white pine and eastern hemlock in northern New York. He recognizes, however,

that the present financial values of standing trees cannot be used alone without consideration of ecological factors which may sometimes be of primary importance in determining marking.

Taylor (1937 and 1939) developed a tree classification for lodgepole pine based on vigor classes. Age, though admittedly a factor influencing the growth capacity of lodgepole pine, could not be accurately recognized from external appearance. Furthermore the

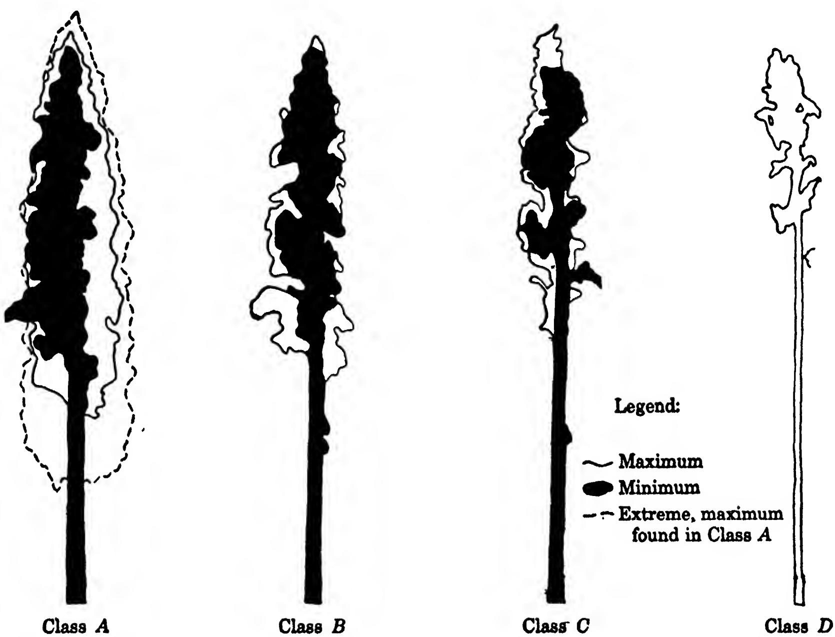

FIG. 70.

Taylor's lodgepole pine tree vigor classes. (Taken from *Jour. Forestry* 37:778.)

age range in the lodgepole pine stands in which timber cutting is carried on is too small to justify using age as a primary factor in the tree classification. In other words his classification really covered only what might be termed the mature age class. Taylor found significant differences in growth rate between his 4 vigor classes both before and after cutting. He finally drew up a marking policy for the lodgepole pine type in Colorado and Wyoming, based on the conclusions of his study and to be applied with the aid of his tree classification. Taylor's tree vigor classes are shown in Figure 70.

A tree classification for northern hardwoods, particularly sugar

maple, has been developed (Stott *et al.* 1942), one purpose being to furnish a guide for correctly marking the timber. This is based on (*a*) the present lumber value of the tree and (*b*) its growth capacity coupled with the risk of non-survival for a future cut. Age is not a factor in the classification, but it is evident that the classification is made up for forests with a narrower total range of ages than occurs in the virgin ponderosa pine type where Keen's classification applies. There are 4 value groups and 4 vigor and risk groups, giving 16 possible tree classes. The crown class of the tree and the evidence of disease play an important part in determining the vigor and risk rating, as is to be expected in a region where rainfall is sufficient to support a closed forest and where heart rots are prevalent.

Silvicultural Clauses in Timber Sale Contracts. Written contracts covering the sale and logging of forest products are always desirable and are virtually indispensable for controlling cuttings in large operations. However, even under a written contract both inspection and the marking of the trees to be cut are usually essential. As recently as 1915 silvicultural clauses in timber-sale contracts were practically unheard of. Nowadays, primarily through the activity of the United States Forest Service in selling timber on the National Forests, such clauses are frequently found, and their use is increasing in contracts for sale of timber from private as well as from public lands. These clauses cover a variety of points, as anything affecting future crop production may be considered to have silvicultural bearing. Included among the items covered and often elaborated on in considerable detail are such matters as method of designating the trees to be removed, fire control, disposal of slash, permissible methods of logging, prevention of damage to young growth and reserved stand, disposal of diseased and defective trees, provisions for restocking the cutover area either artificially or naturally, and arrangements either right after the cutting or a few years later for the cultural operations necessary to establish the new crop.

Control of Waste and Destruction in Logging. Waste and destruction of timber in the logging are likely to occur in any operation. From the silvicultural standpoint such losses are important because they decrease the yield from the area at the present cutting and may lessen the possible production in the future. The waste and destruction may be classified under the following four headings:

1. Material left in the tops through failure to utilize the trunk up to the minimum merchantable top diameter.

2. Material left in the stumps through failure to cut them to the lowest possible limit.

3. Material left in partially unmerchantable (cull) trees, including windfalls and dead trees, through failure to utilize the merchantable portions of such trees.

4. Destruction of the unmerchantable growing stock (and merchantable trees not designated for cutting), either for material to use in the logging operations for such purposes as skids, corduroy roads, and bridge construction, or in order to facilitate the logging work.

Nowadays waste under the first three headings is considered evidence of an inefficient logging operation. As a business proposition, the lumberman may be expected to remedy this defect in his operations, as soon as it comes to his attention, without necessarily adopting the practice of silviculture. Close utilization of material in tops and cull trees is indirectly of silvicultural benefit by reducing the amount of inflammable material in the forest and by removing trees that might harbor destructive insects and fungi.

In judging whether material is being wasted in high stumps, big tops, and partially unmerchantable trees, careful consideration must be given to what constitutes merchantability in each locality. Local conditions governing the logging operations or existing in the available markets may necessitate two different sets of standards, as to minimum top diameters, maximum height of stumps, and extent to which cull material can be utilized, for operations only a few miles apart.

Destruction of the unmerchantable growing stock is of more vital silvicultural importance than the other classes of waste. Reduction in the growing stock, from seedlings right on up to trees just under the cutting size, is likely to result in a lower production in the future crops. The lumberman, unless he is also a grower of timber, rarely is interested in saving the unmerchantable growing stock at the expenditure of any trouble or actual outlay. Where unmerchantable trees will reach merchantable size within a few years he may see a fairly early profit in saving such trees, but in reproduction and young growth as a whole he has no interest. Intention to practice silviculture must exist if the unmerchantable growing stock is to receive protection.

A certain portion of the unmerchantable growing stock may have to be sacrificed in the logging operation, depending upon the difficulties of logging, the quantity and location of the young trees, and the intensity of the silviculture. The proportion which must be sacrificed should be determined before the cutting, and destruction should be kept within prescribed limits.

As already stated, the unmerchantable growing stock is destroyed

either for material to use in the logging operations or to facilitate these operations. Material for use in logging operations is taken from the young trees for skids, construction of skidways, corduroy roads, and other logging requirements. A supply of this material is essential for efficient logging but oftentimes can be secured with little if any added cost from inferior species, tops, or cull material.

In facilitating logging operations, seedlings and small trees are cut or destroyed if they interfere with the choppers, sawyers, or skidding crews, and merchantable trees are likely to be dropped in the direction of their easiest fall, regardless of the young growth which may thereby be smashed.

Given the inclination on the part of the operators a large proportion of this class of destruction can be eliminated.

Certain methods of power logging are especially destructive, in skidding operations, to young growth (for example the high lead system with high-speed engines) and should be displaced by other methods of logging. Show (1926) found in the California pine region that the high lead system was very destructive, whereas tractor logging and animal logging were not. Tractor logging in most forest types is likely to prove cheaper than logging with heavier power machinery, except possibly in clearcutting timber composed of trees of enormous size. Hence some of the more destructive methods are destined to be used less in the future or have already been discarded, for reasons other than their damage to the forest. Furthermore, as the practice of forestry increases the forester will obtain more and more authority to determine the methods of logging to be applied on a given cutting area and can eliminate the more destructive methods. Already the United States Forest Service, in selling timber on the National Forests, is specifying in its contracts the logging methods that are permissible.

It is unreasonable to expect that all reproduction and young growth on cutting areas can be saved. A portion will inevitably be destroyed or injured. The greatest destruction of unmerchantable growing stock is likely to occur in stands of irregular form, where trees of various ages from small seedlings on up are intermingled. In the selection method this situation is especially acute. In removal and final cuttings of the shelterwood type dense masses of reproduction are often on the ground, but here considerable losses in percentage of the total reproduction will not prove critical if they are well distributed over the area. Under the clearcutting method, there is little likelihood of seriously injuring the younger age classes in the logging operations, since they are on areas apart from the mature

timber. In skidding timber, passage through these areas must of course be prevented or kept to established roads.

In cuttings of the selection type, where loss of reproduction and young growth is most likely to imperil continuous production, what percentage of destruction can be regarded as unavoidable and a necessary consequence of harvesting timber? No set figure can be given. Instead every operation must be judged on its own merits. Usually loss has been estimated on the basis of the number of stems destroyed or injured expressed as a percentage of the total number. The really significant point is distribution. If, for example, every milacre on which reproduction is needed has one well established seedling, the area may be fully stocked and the loss from logging be of no account even though 70 per cent of all the seedlings on the area were destroyed. On the other hand a loss of 10 per cent of the total might be so concentrated as to leave large openings entirely without trees.

Direct skidding of logs with horses, particularly where the timber is small enough to be handled by one horse, does so little damage to reproduction and young growth that it can be disregarded. Horse skidding with high wheels is somewhat more destructive but still not unreasonably so. Trimble (1942) and Westveld (1931) give figures for horse logging in spruce and fir stands in the Northeast which indicate that less than one fifth of the spruce and fir reproduction was destroyed in the logging.

Tractor logging can be very destructive. On the other hand, if properly organized and supervised, it need not destroy reproduction and young growth on as much as one third of the cutover area. Frequently the damage will be much lower. In a study of ponderosa pine logging operations in central Idaho, where skidding was done with tractors and long logs were handled, Mowat (1940) found that the percentage of the area stocked with trees of any size was reduced from 78 per cent before logging to 65 per cent after logging on areas where logging slash was left untouched and to 49 per cent after logging on areas where slash was piled and burned. He found that destruction, due both to the felling and skidding and to the slash disposal, could be lessened by proper regulation and closer supervision of the operations.

Worthington (1939) reports, in partial cutting of shortleaf and loblolly pines, damage from felling to be 7 per cent dead and 5 injured and from tractor skidding only 1 per cent dead and 6 injured. These figures were only for pine 5 inches in diameter and larger, young growth below this size and reproduction not being considered in this

study. Although some of this damage could have been avoided by closer supervision, the total is not unreasonably high.

To secure satisfactory results in reduced damage to reproduction and young growth, tractor logging must be carefully planned in advance and kept under close supervision. If certain fairly simple rules, discussed in the next paragraph, are observed, the damage under any type of tractor logging should be held to a reasonable amount (Weidman 1936).

Main tractor roads should be laid out before cutting. They should if possible be straight and yet avoid clumps of young growth. Trees should be felled to or from the roads so as to avoid unnecessary turning of logs, but they should not be felled into clumps of young growth. Swamping should be eliminated, except as much as is needed around log landings. Tractors should be turned in openings if possible and then backed to the load. They should not be driven across from one road to another. Logs should be pulled out endwise and not siwashed around trees or clumps of young growth. Two logs should never be hooked together at the same cut and then pulled out sidewise. Tractors should be equipped with a drum and short skidding line for pulling logs out, instead of driving in to them.

Damage in felling, which occurs under all logging methods, can be reduced by not dropping trees upon advance growth or, if this cannot be entirely avoided, by scattering the trees so that the damage will be distributed and be in effect a thinning of the stand.

In the last analysis, when stands containing reproduction and young growth are being logged, genuine cooperation on the part of the felling and skidding crews is essential for keeping damage at a low figure.

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CHAPTER XV

SLASH DISPOSAL

Definition. Slash is understood to include all the debris left in the forest as the result of cutting or agencies such as wind and fire and comprises the tops, branches, and unutilized portions of the trees cut, together with other trees uprooted or broken off in the process or as a consequence of the logging. A broad definition of the term includes also dead trees and windfalls on the ground previous to the logging. Slash is created not only as a result of cutting, but also as a result of other destructive agencies, the most important being fire and wind, which may cause the death and overflow of a large portion of the stand.

Silvicultural Effects of Slash. Slash as defined above consists of such a variety of material that it is best to divide the total into several classes before discussing its silvicultural effect.

1. Material which decays rapidly; small branches and tops and foliage.
2. Large branches and tops.
3. Logs and unused portions of the bole.

The relative amounts of the different classes of material on a given area show wide variations depending primarily upon the conditions governing utilization of forest products. With intensive utilization the slash that remains may consist only of foliage and small branches. In rare cases even this material may find utilization as brushwood.

Slash may be further distinguished as originating from either coniferous or broadleaf species of trees. Of the two the conifer slash makes the denser cover, lies lower, remains sound longer, and on the whole is a greater menace than hardwood slash, which often makes an unsightly tangle loosely occupying considerable space but is not potentially so much a source of danger. Hardwood slash absorbs moisture faster and goes to pieces more quickly. This process ordinarily is so rapid as not to justify any expenditure for hastening the result. For these reasons disposal of hardwood slash is rarely undertaken.

The silvicultural effects of slash in a narrow sense may be restricted to the direct effect upon the soil and reproduction. Under this in-

terpretation slash disposal has separate and distinct silvicultural, fire, entomological, and pathological aspects. As a matter of fact, the production of better tree crops is the basis of the forester's interest in treatment of slash. Forest fires, insects, and fungi are destructive agencies whose action is directly and primarily to affect production of tree crops. Hence the influence of slash upon these destructive agencies is of silvicultural importance and, together with its more direct influence upon soil and reproduction, is properly discussed under the silvicultural effects of slash.

Slash in Relation to the Soil. The effect of slash upon forest soil is on the whole beneficial. It prevents erosion and landslides by holding the litter and soil in place and by mechanically obstructing the movement of water and soil. It holds the snow in spring and may prevent frost heaving. Through the process of decay it adds to the organic matter in the soil and as a consequence should tend to increase its productivity, particularly on soils deficient in humus. In many instances slash improves conditions for the activity of soil fauna and various microorganisms which add to soil fertility. Where an excess supply of undecomposed litter covers the ground the beneficial influence of slash is least. In cold climates slash may be injurious by reducing the light and heat which reach the soil. On bare soils and on steep slopes at high altitudes the protective value of slash is greatest.

Slash in Relation to Reproduction. Slash exerts an influence upon reproduction sometimes beneficial and sometimes unfavorable, depending upon the amount and characteristics of the slash and the individual climatic and biological conditions. Where slash is so abundant as to occupy a considerable portion of the area it is certain to have an important relation to reproduction. The method of slash disposal may control the composition of the new crop which starts after cutting.

The beneficial effect of slash is to encourage the start and early development of reproduction: (*a*) by the conservation of the moisture in the surface soil through the protection afforded by the slash against sun and wind; (*b*) by the creation of desired seedbed conditions through shading and through the increase in humus and litter (derived from the foliage of the felled trees); (*c*) by the protecting shade afforded young plants; and (*d*) by the mechanical protection given the seedlings against the trampling and browsing of animals.

The harmful influence of slash upon reproduction is its action as an obstacle to germination or to early development of the young plants, either directly as an obstruction or indirectly by encouraging other

vegetation in competition against the tree seedlings. Slash, where it lies thickly, may mechanically stop the growth of reproduction which started previous to the cutting or prevent establishment of new seedlings. Sufficient heat for germination of seeds to take place may be lacking on account of the amount of slash, or the seedbed created may be unfavorable. If germination does take place, the seedlings may not survive under the conditions created by the slash. A dense cover of slash usually prevents the establishment of reproduction, often for several decades. The beneficial effects of slash upon surface moisture content and soil fertility may react to stimulate grasses or herbaceous plants to a greater extent than it encourages tree seedlings, thus favoring the competition of grasses and herbs against the tree reproduction.

Slash in Relation to Forest Fires. Unquestionably slash is dangerous from the fire standpoint for it is one of the most important sources of inflammable material. In addition to the slash the litter, ground cover, underbrush, living trees, and snags or standing dead trees furnish quantities of inflammable material. In many instances the slash provides the largest portion of the potential fuel. The foliage and the small branches are easily ignited and may burn rapidly, but the larger limbs and logs cannot be kindled as quickly or burn as rapidly, although when once started they will create more heat, burn for a longer time, and in general, other conditions being equal, make a more severe fire than could occur on the same area without slash. With conifers, which retain their foliage for some time after felling, the slash may be easily ignited for several months by simply touching a lighted match to the foliage. This is particularly true on heavily cut areas where the cutting itself results in opening the stand to the drying action of sun and wind, thereby increasing the inflammability of the fuel.

Ordinarily the litter or ground cover provides that portion of the available fuel which is most easily ignited. A fire is likely to start in this material (even on areas covered with slash) and then spread quickly to the slash itself. The larger material included in the slash, when once set on fire, may make an exceptionally serious conflagration, which may gain such impetus as to sweep through adjacent green timber.

The prevalence of fires on cutover areas should not be attributed wholly to the presence of slash. The cutting itself increases to a marked degree the inflammability of the area. Sun and wind are admitted and act as drying agents on the litter, ground cover, and underbrush, as well as upon the tops of the felled trees. The opening

of the stand encourages a growth of grass and weeds, providing additional fuel for the flames.

Besides furnishing a large part of the inflammable material, slash renders the fighting of fires difficult and dangerous. A slash-covered area cannot be traversed quickly, and the fighters may be caught if in the path of the fire. More labor is required to prepare lines for checking the fire, and it may be impossible to use methods of control which would be feasible on areas free from slash.

Slash in Relation to Insects. At one time it was believed that slash furnished a favorite breeding place for species of insects capable of destroying living timber (Anonymous 1927) and that from the slash the insects migrated to nearby living timber and caused severe losses. Careful investigations by forest entomologists have changed this idea. It is now held that any operations which result in the cutting of living timber exert a powerful attractive influence and bring into the neighborhood many species of insects, particularly the highly dangerous species of bark beetles attacking the pines and spruces. The newly cut stumps, logs, lumber, and other forest products together with the slash exercise this attractive influence. Thus the slash alone is not responsible for attracting the insects, although it may remain on the cutover area after the merchantable forest products have been removed. In spite of the attractive power of the slash and its continuing presence on cutover areas the evidence indicates that, with few exceptions, the dangerous insects do not breed in the slash and then migrate to living timber. However, the concentration in a locality of dangerous insects attracted there by the freshly cut trees may result in attacks on living timber of greater than normal severity, particularly when the supply of freshly cut trees fails at the cessation of a logging operation.

It is recognized that many species of insects breed in slash, but very few such insects are capable of attacking living timber. Those which can attack living timber are enemies principally of pine, spruce, and Douglas-fir. The relatively few destructive insects which may breed in slash do so almost exclusively in the tops, logs, and larger limbs included among the slash and not in the small limbs which constitute the disposable portion of the slash.

The direct effect of insects upon the slash itself, in accelerating the process of decomposition, is beneficial.

Slash in Relation to Fungi. The slash acts as host for a variety of fungi all of which are beneficial in hastening decay of the slash. The length of time required for fungi to accomplish decomposition of the slash is of course subject to wide variation and depends upon

a number of factors among which climate, species of tree, attacking organism, and distribution, amount, and nature of the slash are among the more important. For slash to decompose so that it does not add appreciably to the heat of a fire or interfere measurably with the start of reproduction may take from 2 to more than 40 years.

Relatively few of the fungi which thrive in the slash are capable of attacking living trees. Sporophores may be produced on the slash and may scatter spores of dangerous species of fungi which cause infection of standing trees. The fungi which are most virulent and destructive to living trees develop principally in the larger pieces of the slash. In warm and humid regions favorable to the development of fungi, the danger to trees on the area and in the adjoining forest of infection by destructive diseases developing first in the slash is at the maximum.

Slash in Relation to Forest Esthetics. From the standpoint of forest esthetics the presence of slash is a nuisance. It spoils the appearance of the forest. There are many places where this factor has little weight. In connection with the handling of public forests the idea of partial cutting, as contrasted to clearcutting, and development for recreational purposes is gaining ground. This means that increasing attention will be given to forest esthetics.

Methods of Slash Disposal. Widely diverse methods have been developed for treatment of slash to meet the requirements of all conditions encountered in the field. The principal ones are discussed here. Details of applying any method will vary in different forest types.

Disposal of Slash by Swamper Burning (Known also as " burning as the logging proceeds," " live burning," " forced burning," or " progressive burning "). The practice in this method is to carry on the work of slash disposal soon after the trees are felled and bucked up into logs. Fires are started at convenient points, and the limbs from the felled trees are placed on the fires and burned up. The felling crews may do the work or special men may be assigned to the duty.

If the burning is done as the felling is carried on the method is termed " live burning." This work may well be added to the duties of the men who limb out the trees. Live burning can be carried on successfully in rainy weather and in snowstorms. If it follows the felling and bucking by several days, special men must be employed. Immediate burning is more likely to link slash disposal up closely to logging operations as a necessary detail and result in greater efficiency and ease of supervision. As few fires as possible are made, and they are so located as to cause the minimum injury to reproduction

and the remaining stand. Where the work of slash disposal is left till just after the logs are skidded the method is termed " forced burning."

Swamper burning has several advantages over other methods. It reduces the fire hazard promptly after logging to the minimum practicable by slash disposal. When done before the logs are skidded it should cheapen the cost of this operation if animal logging is practiced (Marshall and Cummings 1927). The cost of swamper burning with other logging methods than animal logging approaches that of piling and burning in a separate operation. In some cases it has been found cheaper; in others a little more expensive. As compared to piling and burning, it saves one operation, and the limbs, being thrown right on the fire, do not have to be cut up so small or piled so carefully. Less of the area of the stand is actually burned over than in most other methods (Munger and Westveld 1931), since the tendency is to have fewer fires and thus burn more slash on one spot than would be placed in a single, compact brush pile. Reproduction and larger trees suffer less injury than in any other method of slash disposal requiring the use of fire.

An interesting illustration of the comparative damage to reproduction, in an all-aged jack pine stand logged for fuelwood, from application of several methods of treating slash is found in a *Technical Note* of the Lake States Forest Experiment Station (Anonymous 1934) from which the data in Table XX are taken. These data, though of course true only for the one stand, yet illustrate what light injury swamper burning, with its quick cutting and burning of slash, may do and how slash left as it falls (undisposed) may smother quantities of reproduction.

TABLE XX

Method of Slash disposal Followed	*Percentage of remaining stand*		
	Undamaged	*Injured*	*Killed*
Swamper burned	96	1	3
Piled and left unburned	89	2	9
Piled and burned	74	8	18
Lopped and left unburned	65	9	26
Undisposed	56	12	32
Broadcast burned	12	10	78

The chief objection cited to swamper burning is that it is inapplicable when the forest is dry and there is danger of spreading fire. As a matter of fact this holds true of any burning operations

for disposing of the slash. During the entire year there will be more time suitable for burning brush by swamper burning than by any other burning method. In operations which run throughout the year, some other method of slash disposal not requiring immediate burning may be needed part of the time in the hot dry seasons.

Swamper burning is likely to find increasing use because of its various advantages.

Disposal of Slash by Piling and Burning. The tops and limbs of the trees are placed in piles, which are burned later in a favorable season. The logger in the ordinary course of his work, to keep the slash from hindering operations, throws it into loose piles or windrows. This is essential if the amount of slash is large and the timber is removed from the felling area by animal power. Even if power logging is employed, the final result is to leave the slash irregularly bunched rather than uniformly distributed over the area. Such treatment should not be confused with a piling method under which the slash is piled systematically and the area it occupies is greatly reduced.

In piling brush the proper places at which to locate piles are selected and the brush is piled on these spots. Before slash can be piled the large tops and limbs are often cut up and reduced to small enough size to be easily handled and closely piled. However, the expense is increased where much cutting up of the limbs is necessary.

The piles should be compact and relatively small as compared to the large heaps of tops often left after logging. Very large piles are more dangerous to burn than small ones and usually require the brush to be carried farther. Munger and Westveld (1931) advise, for ponderosa pine, piles 8 to 10 feet in diameter and 5 to 6 feet high, which are more economical to make and to burn than smaller piles.

Loose piles are difficult to burn cleanly and occupy too much space.

Piles usually are circular and somewhat conical in shape. With some species the slash packs together better when the branches are laid all in one direction, making a relatively long, rectangular-shaped pile. For this arrangement most of the limbs need not be cut up but are piled full length. If a quantity of fine material is placed at the bottom of the pile it may assist in kindling the fire later on when the pile is burned.

The piles, particularly those of the conical type, must be carefully built because they may have to stand several months to a year before the time for burning arrives. If they are thatched on top with small branches, rain and snow will be shed efficiently rather than absorbed.

It is unnecessary and impracticable without considerable expense to place the entire volume of the slash in piles. The more inflammable portion, consisting of the branches up to approximately 4 inches in diameter at the butt, should be piled, with such twigs and foliage as are retained. The large branches, cull logs, and windfalls and other unutilized trees are not put into the piles. They may be left lying in contact with the ground where they absorb moisture and usually decay more quickly than if elevated.

If animal logging is employed, piling of slash while the cutting is in progress and before the logs are skidded has the advantage of facilitating the logging since the ground is somewhat cleared of debris. Green slash is easier and cheaper to pile than dry slash. On the other hand, if the slash is piled after the skidding the piles are less likely to be knocked down, the brush is not held down by logs, and piles can be placed in the skidding trails. Usually piling after skidding is preferable. The work should be done immediately after the skidding, while the slash is still green, and preferably within 5 to 10 days after the trees are felled.

Brush piles, if made before the skidding, should be located so as not to be knocked over by this operation and (if they are to be burned) at safe distances from reproduction and larger trees. Occasional piles which have to be made close to live trees may be left unburned. If the piling is not done until after the completion of the logging many of the piles can be located in roadways and yards. Where undesirable reproduction, underbrush, or trees of inferior species are to be destroyed the piles should be located so as to kill this material. Sometimes a stake is set up by the foreman to designate the location of each pile, thus saving the time of the crew and securing better locations which may cheapen cost.

The piles are burned as a special piece of work distinct from the piling. During dry seasons of the year it is dangerous to carry on any slash-burning operations. As a precaution the piles made in such periods are not burned until later and only when climatic conditions are such as to render the operation safe. An ideal time to burn brush piles is immediately after the first rain or snowfall, which is likely to be so light as not to prevent easy burning of the piles, although affording protection to surrounding trees.

Burning a large number of brush piles is at best a risky operation. There is danger that the fire may become uncontrollable and spread from pile to pile, until finally it has gained such momentum that it cannot be held on the cutover area but spreads into adjacent uncut timber. Reproduction and young timber standing near the piles may

be injured or destroyed by the heat even though the fire does not spread from pile to pile.

This is particularly likely to happen if a group of adjoining piles is burned all at one time. The air becomes so heated and such a draft is created that the larger trees and the reproduction on the area may be killed. A better arrangement is to burn piles here and there and not to set fire to the adjacent piles until those first lighted have been consumed. If a wind is blowing the burning should be started among the piles on the leeward side of the cutover area. On slopes the burning should start at the top and progress downward.

If a large number of brush piles must be lighted a special brush-burning torch is useful. The torch should be rigid and strong enough to be thrust into the piled slash without injury to the handle or to the torch proper and should be capable of burning for some time. Excellent torches made out of gas pipe can be purchased or made locally. These torches are designed to hold a supply of kerosene oil and have a wick in the lower end.

More elaborate torches burning kerosene or other liquid fuels under air or gas pressure and producing a hot flame 12 to 30 inches in length and up to 2000° F in intensity are sometimes employed for burning slash. Such a device usually includes a tank to be carried on the back and is quite heavy when full of fuel. Ability to ignite green slash too wet to burn by other methods is the chief advantage claimed for torches of this type. Where the topography is rugged, the underbrush abundant, or the brush easy to ignite, the bulkiness of these torches and the attention and expense needed to keep them functioning properly make simpler torches preferable. Kerosene or other kinds of oil can be carried in an ordinary back-pack pump, such as the Smith-Indian, and be sprayed on the slash. A flame-thrower attachment can be substituted for the ordinary nozzle, or a man can follow the pump lighting fires by hand. If the slash is dry, faster progress can be made under this plan than when one of the heavy-type torches is used. Some men prefer a supply of kerosene oil or pitchy kindlings for starting the fires or employ home-made torches of their own invention.

If the piles are well built they should burn completely without any attention after lighting. Otherwise the partially consumed piles must be visited while still burning and chunked up by having the unconsumed brush around the edges thrown onto the fire.

Where it is essential to burn wet brush piles they may be treated with such special fuel combinations as a mixture of 40 parts Diesel oil and 60 parts charcoal. This method has been successful in burn-

ing brush in *Ribes* eradication work in northern Idaho (Offord and D'Urbal 1937). As a method for disposal of slash after logging operations, it is impractical for general use at the present time because of the cost.

Piling and burning has in the past been the method of slash disposal most widely used and approved. When properly applied it results in only slight injury to advance reproduction and other standing trees. The fire hazard is eliminated as thoroughly as by swamper burning but not as promptly.

Piling and burning is as expensive as or more expensive than swamper burning. A difficulty in applying piling and burning over large areas is that only short periods in the average year can be found suitable for the purpose of burning the piles. The ideal combination of dry slash piles with ground and surrounding forest wet enough to make burning safe is hard to find. Such periods may come suddenly and end quickly. If the amount of slash to be burned is large, it may be physically impossible to complete the burning in the suitable periods. For this reason and because of the relatively high expense, it is likely that other methods of slash disposal may find more general favor in coming years.

Disposal of Slash by Piling without Burning. Under certain circumstances it may be desirable to pile the brush and allow it to remain indefinitely on the area without burning. Eventually the piled slash will decay and disappear but only after many years. The method is of limited application but is likely to find its chief use in localities where the burning of piled slash is exceptionally dangerous from the fire standpoint.

Disposal of Slash by Broadcast Burning. In broadcast burning fires are started and allowed to burn over the area occupied by slash. Around the edges of the cutover area it is sometimes, but not always, necessary to clear firebreaks of slash and other inflammable material. If the area is extensive interior firebreaks may be needed, dividing the area into blocks or units each of which can be burned over in a single day. Natural firebreaks or trails opened in the logging will frequently serve the purpose without expenditure for special firebreaks. In any case the boundaries of the area to be burned over must be definitely known, and preparations must be made to stop the fire at these boundaries. If firebreaks are used, the size of the blocks will depend on conditions, among which the amount and inflammability of the slash and the difficulties of controlling the fire are of primary importance. Davis and Klehm (1939) consider approximately 200 acres the maximum size for a single block. Should

there be on the area any trees which it is desired to save the slash must be pulled away from them. A fire hot enough to consume the slash is likely to destroy all reproduction and trees on the area covered by the fire. It may consume all the litter.

When many standing trees and considerable young growth are killed by the broadcast burn, the fire hazard may be increased rather than lessened, for the killed trees are not likely to be completely destroyed and are more of a fire hazard dead than alive. Such a combination is likely to occur only in forest types where either broadcast burning has no legitimate place because the young growth and older trees left after cutting are wanted in the future crop or the larger material left on the area consists of inferior species or cull trees. In the latter situation it may be necessary to fell the trees of inferior species and unmerchantable trees in order to obtain a clean burn.

Broadcast burning is a dangerous method of slash disposal because, unless carefully controlled, the fire is likely to gain momentum and escape to adjoining timbered areas. For this reason the time of burning must be chosen so as to secure favorable climatic conditions. Late afternoon or early evening is the best time for broadcast burning. The ideal time for burning may be stated as a period with no wind or a little wind coming steadily from one direction, relatively high humidity, low temperature, and cloudy weather immediately preceding a period of rain or snow. This combination is difficult to attain with certainty, but the nearest approach to the ideal is likely to be found by selecting for the operation an afternoon or a night in the early spring or late fall when there is a probability of rain or snow to follow. Fall is the more effective and safer time to broadcast-burn.

An excellent summary of the reasons for broadcast burning in the fall rather than in the spring with Douglas-fir in the Pacific northwest is contained in the following quotation (Anonymous 1933):

"In most instances early spring burns are not considered safe or even good burns in western Washington, for the following reasons:

"1. Following the winter's rain, the slash has absorbed such a percentage of moisture that even with the low humidities often recorded in April periods, little of the actual slash is consumed. The solid material retains much of its moisture content and so is not consumed by fire.

"2. Early spring burned areas have a distinct tendency to hold fire in snags and down logs, which under changing weather conditions may break out, spread and create damage later in the fire season.

"3. A slash area blackened by a spring burn 'generates' a ground

temperature several degrees higher than an unburned area. This is due to the heat absorbing capacity of any dark colored material.

"Under these conditions, a very rapid drying out takes place on such areas as the fire season advances, and with but little quantity reduction in slash or debris, the stage is set for a more rapidly spreading fire, in case of accident, than would have been the case if a spring burn had not been set. This is, of course, true only for the first year, but has particular application to hang-overs.

"The period following a spring burn normally tends towards the hotter and dryer months. The chances of a hang-over fire are thus increased, as compared with the fall burn, when the seasonal rains have arrived or are actually forecast."

An adequate force of men with appropriate equipment should be on hand to set the fires and watch their progress, and in addition, if the area to be burned over is extensive, it is advisable before burning to have arrangements completed with a larger force of men to come out at once in the event that the fire escapes. The crews in nearby lumber camps are logically the men for such an emergency force. Patrol may be needed for several days after the completion of the burning.

A variety of techniques has been developed in conducting the actual broadcast burning of the slash. On steep slopes the burning should begin at the top and advance downward in progressive strips. A string of fires may be started along the extreme upper edge of the clearing and allowed to burn out to the firebreak and to work downward. Sometimes to get a clean burn it is necessary first to start a string of fires 25 to 100 feet down from the top and allow them to start up toward the firebreak before fires are set right along the edge of the firebreak. The purpose of both methods is to obtain a burned-over strip along the top of the slope next to the firebreak before the main area lower down the slope is fired. When a strip across the top has been burned over, another string of fires is set 100 to 200 feet below the first and a second strip burned out. In this way the slope is covered progressively.

On level land fires may be set along the leeward side of the clear-cut area. The fires so started are prevented from crossing the firebreak and are forced to burn against the wind. A better method, oftentimes, is to take advantage of the upward draft created by the fire itself and start one or more fires in the center of the clearing. These fires soon suck the air in from all sides and tend to prevent the fire from being blown by what little wind there may be into adjoining timber. Davis and Klehm (1939) term this method "center

firing" and advise its use in the western white pine region on flats and slopes of less than 30 per cent. As described by them the method, when used on areas larger than 10 acres, calls for the setting, after the center fires have gained headway, of a second line of fires located 100 to 200 feet inside the boundaries of the clearcut area. These fires are drawn toward the center fires by the draft and also burn out slowly to the edges of the clearing.

Broadcast burning is usually a cheap method of disposal for it requires no piling and very little handling of the slash. From a few cents to $2 per acre represents the usual range in cost. Since the stand is heavy on areas where broadcast burning can be employed, the average cost per thousand feet, board measure, cut is small (2 to 5 cents). When both the construction of firebreaks dividing the area into small blocks and the felling of unmerchantable trees are required, the maximum costs occur. When so conducted broadcast burning may become an expensive method of slash disposal. In the western white pine type Davis and Klehm (1939) estimated the cost at $29 per acre for slash disposal, of which $22 represented the expense of felling the standing trees (mainly inferior species) which had to be cut in preparation for the broadcast burn. An additional $10 per acre for restocking the area by planting is a necessary item since the broadcast burn makes natural regeneration uncertain. The method is recommended for this forest type only if it is desired to eliminate the inferior associates of western white pine in the new crop.

Broadcast burning as a method of slash disposal is so destructive to reproduction and to all standing trees and is such a source of danger to the adjoining forest that, in spite of its usual cheapness, the method should in the future be restricted to cutover areas particularly adapted to its use. The Douglas-fir type of western Oregon and Washington, where clearcutting is still employed on a large scale, is one of the few forest types in this country where slash disposal by broadcast burning is justified. Here the enormous accumulations of slash after logging make other methods of reduction impractical. Munger and Matthews (1941) estimate an average volume of 126 cords per acre of coarse and fine debris left after logging on areas they examined. The only alternative to broadcast burning of these huge volumes of slash would be leaving the material untouched, as it lies after logging, and spending money for relatively intensive fire control, which the region is as yet not prepared to undertake.

Munger and Matthews recognize that, except as a fire-hazard-

reduction measure, broadcast burning in Douglas-fir forests cannot be recommended. Natural regeneration is better when the slash is left untouched.

Spot burning is a modification of broadcast burning intended for use where it is desired that the whole area should not be burned over. Under this plan only the portions of the cutting area which are located in particularly dangerous situations or are covered with especially heavy slash are burned broadcast. It has been applied principally in the Pacific northwest. The danger in spot burning is that the fire will spread and become a broadcast burn over the entire clearing. The most favorable conditions for spot burning occur where patches of slash dense enough to burn without piling are interspersed with areas relatively free of slash.

Disposal of Slash by Lopping. Lopping consists in cutting up the slash into smaller pieces, which are then left on the ground. In order to have practical value, the term must be made more definite in accordance with the specifications holding in the given locality. For example, the top-lopping law of New York State requires that all limbs 3 inches and over in diameter be severed from the trunk and that tops be lopped down to the 3-inch point. In theory lopping is designed to cut the slash up into pieces of such size and shape as will lie in close contact with the ground, where they will absorb moisture and decay more quickly. This will not hold true always, as under some conditions tops decay faster when left intact than they do when lopped.

The terms "lopping and scattering" and "scattering" are sometimes used to characterize modifications of the lopping method. They are not sufficiently distinctive to merit classifications as separate slash-disposal methods. A scattering differs from a lopping method of disposal in that no cutting up of the limbs and tops is required, but a conscious effort is made to scatter them over the cutting area. Lopped limbs lie in closer contact with the ground than the limbs left after a scattering. In lopping alone the limbs and tops are left as they lie after being lopped. Lopping and scattering combines the two operations of lopping and distributing the material over the area. During the hauling out of the logs the lopped tops are likely to be thrown together into loose heaps, and so, if scattering is used, the scattering must be done as the final step after the logs have been yarded. The best time to carry on the lopping is in connection with trimming the bole and bucking up the logs.

Lopping is usually considered a cheaper method of slash disposal than methods involving piling. This is not invariably true. If

careful scattering of the slash is included after the lopping the cost is likely to be higher than piling and burning. The cheapest use of the method involves no scattering of the slash. The most expensive employs both lopping and scattering.

By allowing the tops to decay, the lopping method improves soil conditions, increases the humus content, and acts mechanically to prevent erosion. Except for seedlings which may be covered by the slash the existing stand on the cutover area is not injured by lopping. Skidding the logs is made easier and cheaper where the slash is cut into small pieces and hence easily moved. A tendency toward closer utilization is developed, because where the bole must be trimmed of branches up to a small diameter limit in the lopping the operator is likely to use more of the bole than he otherwise would. Fire fighting is easier in lopped than in unlopped slash because of the ease and speed with which the lopped slash can be handled.

A disadvantage is the fact that until the lopped tops decay a serious fire hazard may exist. The length of time necessary for the tops to absorb enough moisture or decay sufficiently to cease being a fire hazard varies with the climatic conditions, the amount of the lopped material, and its contact with the ground.

Disposal of Slash by Pulling the Tops. Pulling the tops consists of dragging the entire unutilized tops of the tree to positions on the area different from those occupied by the tops when the trees were felled. None of the slash is removed from the felling area, but the position of a portion (usually small) is changed. Tops are dragged if they lie in dangerous proximity to standing trees or reproduction, or if they are needed to cover spots likely to be eroded such as gullies or slopes. In some cases the tops are of assistance to reproduction by affording slight shade, a desired seedbed, or protection from the trampling or browsing of animals. The pulled tops, because they stand relatively high above the ground and are able, when burning, to carry flames into the crowns of trees, constitute a more serious fire menace to standing trees than do lopped tops. Pulling is less expensive than lopping and scattering and this is its chief advantage over lopping (Pearson and McIntyre 1935).

The method is of limited application. It has been employed principally in Arizona and New Mexico in some open stands of the ponderosa pine type, in places where the amount of slash was small and there were plenty of open spaces for the pulled tops to be located where they would not endanger living trees in case of fire. It may prove to be of value in stands of southern pines, particularly shortleaf and longleaf.

Light Burning. Light burning is the annual or periodic burning over broadcast of forest areas. It is defined as prescribed burning at intervals of time so spaced that only a relatively small amount of fuel accumulates between such repeated burning, in order that accidental fires will be of low intensity, cause little damage, and be easily controlled. It is an intentional use of surface fires to keep the ground free of highly inflammable material made up of litter, ground cover, underbrush, and reproduction, with the objective of securing for the standing trees better protection against fire, or, in some parts of the country, to improve forage conditions for livestock. Light burning is not a method of slash disposal, being applied more or less independently of cutting operations, and destroying a class of material different from that treated in slash disposal. Slash as previously defined is created mainly as a result of cutting operations. Light burning is discussed at this point because of its similarity in some respects to broadcast burning, with which it sometimes is confused, and because it does have as its objective one of the purposes of slash disposal — namely fuel reduction.

The theory is that, if inflammable material is burned at relatively frequent intervals, a fire hot enough to injure the less inflammable but more valuable material, namely the standing timber, cannot start. Very frequently this is a false premise. In any event, whether a fire seriously damaging to merchantable timber can or cannot be prevented by light burning, the productive power of the forest unquestionably is reduced by repeated light burning. The injuries may be summarized under the following headings:

1. Injury to the soil. Light burning proposes to prevent the accumulation of litter which on many sites is essential for the production of humus, this in turn being of vital importance in maintaining the physical properties of the soil in best condition. Annual burning removes the litter as fast as it forms and may have a serious effect on the humus contents. Periodic burning at intervals of 3 to 5 years is less injurious. Sandy soils with level topography are least injured; heavy soils of fine texture and on slopes which may erode suffer the greatest injury. Under conditions, as in the South, where grasses and legumes may quickly clothe a burned-over area the roots of these plants maintain the humus supply.

2. Injury to reproduction. A fire hot enough to consume the litter and ground cover will kill small reproduction as fast as it starts. In unevenaged stands the result would ultimately be the destruction of the forest. In certain evenaged stands where reproduction is not desired except in the regeneration period, a temporary restriction

of reproduction certainly does no harm and may be of benefit. As the end of the rotation approaches, burning may need to be stopped to allow the establishment of reproduction. The burned-over surfaces may furnish an excellent seedbed for the start of seedlings.

3. Injury to trees above reproduction size. Surface fires damage standing trees in ratio to their size and inherent powers of resisting heat. Large trees and those with thick corky bark may escape injury while small thin-barked trees are killed. The aggregate amount of the damage from even a single light burn often is serious and from repeated burns may result in heavy inroads upon the growing stock. The loss from insects is likely to be increased.

4. Reduction in density of stocking. As a final consequence of the injuries to reproduction, growing stock, and soil, the density of the stand may be reduced to an undesirable degree, and the quality and quantity of production per acre lowered.

In conducting a light burning operation a time is selected when the material is dry enough to burn readily though not so dry as to threaten to ignite the forest itself, and when climatic conditions are favorable for controlling the fire. In some regions it is practically impossible to find this ideal period (Show and Kotok 1924), and consequently the light burning, if done at all, comes when conditions are unsafe. The advocates of light burning minimize the damage done and state that it can be avoided by raking the litter away from the larger trees. This is an expensive operation even if restricted to the larger trees, while to carry on similar raking for the protection of the smaller trees and reproduction is manifestly out of the question. Should light burning be conducted in such a careful manner as to save reproduction and avoid injury to other standing trees, it would become an extraordinarily expensive method of protection when repeated at the necessary short intervals.

Light burning has been practiced chiefly in two parts of the United States: the pine region of California, and throughout the southern states in stands of southern yellow pines.

In the irregular mixed forests of the California pine region, under the climatic conditions prevailing there, light burning primarily to protect timber of merchantable size was early seen to be a dangerous threat to the permanent existence of the forest. As a result of the vigorous campaign waged against it by the foresters and the more progressive lumbermen of the state (Bruce 1923) light burning on forest lands in California has been permanently discredited.

In the southern pine forests the practice of light burning is still common and often has a main objective of making wild forage more

accessible to domestic livestock. The practice can always be applied with greater safety to the forest in evenaged second-growth stands, such as characterize the southern pine region, than in the irregular or unevenaged stands of virgin timber typical of the California pine region, where the reproduction which should be continually developing here and there over the whole area is killed by the burning.

If light burning can safely be allowed in any forest in the United States it will be in stands of longleaf pine. Longleaf is remarkably fire resistant, reproducing often in spite of fire, and grows mainly on level lands with sandy soils relatively free from injury by fire and in a region where under present social and economic conditions the total suppression of surface fires is extremely difficult. Although the immediately apparent injurious effects of carefully applied light burning on the longleaf pine forest and soil are so small as to be negligible in the long run, even here repeated light burnings are likely to be reflected in decreased productive power. When and where total suppression of fires becomes possible at reasonable cost, burning in longleaf pine stands, *as a method of fire protection,* should be discontinued. For other purposes, to assist reproduction for example, prescribed burnings at intervals during a part of the rotation should prove beneficial in the management of longleaf pine and probably of several other species in the United States.

Controlled and Prescribed Burning. With the increasing use of fire in burning over forest areas for the accomplishment of various specific silvicultural purposes (quite distinct from fuel reduction for the protection of standing timber) the terms "controlled burning" and "prescribed burning" have come into use and in fact have virtually superseded the older term "light burning." Controlled burning is defined as any deliberate use of fire on wild land in which burning is restricted to a predetermined area and intensity. It is the most general and comprehensive of the three terms. Prescribed burning is a special type of controlled burning and is defined as the application of fire to land under such conditions of weather, soil moisture, time of day, and other factors as presumably will result in the intensity of heat and spread required to accomplish specific silvicultural, wildlife, or grazing purposes or to reduce fire hazard.

The application of prescribed burning for the accomplishment of specific, accurately defined, objectives is in its infancy. It should find employment in many forest types, just as fast as knowledge of how to use it successfully and as old inhibitions, from the days when protection from fire was considered the principal part of forest management, can be overcome.

Application of Slash-Disposal Methods under Various Kinds of Cuttings. Under any of the various kinds of cuttings it may be true that the best method for disposal of the slash is to do nothing with it. Where complete utilization to a small top diameter limit is economically possible, not enough material may be left in the tops to warrant any special treatment. However, the following paragraphs, unless otherwise stated, assume that some method of slash disposal is going to be employed.

Reproduction Cuttings: Cuttings under the clearcutting method. This is one of the few reproduction methods with which broadcast burning can be employed. No trees are left on the felling area to be injured in the fire. Slash is heavy after a clearcutting, sometimes lying several feet deep over the greater part of the area, and consequently expensive to handle. Ordinarily a clearcutting method is not used unless the species desired in the new stand reproduces well on a bare site free of underbrush and litter. Taking all these facts into consideration, broadcast burning frequently is seen to be the cheapest and most satisfactory method of slash disposal. Conditions may be such that it is unsafe or not in harmony with the silvicultural requirements to burn broadcast. If broadcast burning is not used, swamper burning or a piling method may be employed. Piling and burning later would be chosen only when climatic conditions made it unsafe to burn during the logging operation. Piling without burning is undesirable on a clearcut area, because so much room is likely to be taken by the piles. Lopping of tops is not suitable owing to the relatively large amount of slash on the area.

Cuttings under the seed-tree method. The area is left quite bare with relatively few trees scattered singly or in groups. There are not enough of these seed trees to make broadcast burning impracticable. The expense of the operation will be increased by the necessity of clearing the slash away from the seed trees and burning over the area more carefully. Otherwise what has been said of cuttings under the clearcutting method applies for the seed-tree method.

Cuttings under the shelterwood method. Broadcast burning is impracticable, as it would result in destruction of reproduction and probably of some of the mature trees remaining on the area after all but the final cutting. Swamper burning, piling and burning, lopping, or pulling tops are possible. Where the shelterwood method is intensively applied the slash may be so small in quantity as to require no disposal. If the stand is open and the site is in need of protection even large tops may be dragged away from the standing trees and left intact. The slash usually is light enough to admit of lopping

and scattering without interfering with reproduction. This has the advantage of not requiring the use of fire, which is likely to injure the reproduction already started and also the remaining mature stand.

The lopped tops may form an impediment to the start and development of reproduction, in which case swamper burning or piling and burning is advisable. Care is necessary to conduct the burning without injury to reproduction and mature trees.

Cuttings under the selection method. Under single-tree selection, the amount of slash in any one place is small. Lopping the tops without scattering fits the situation, particularly as single-tree selection is likely to be used on protection sites. In group selection the trees so far as possible are felled in toward the center of the group. The tops can here be swamper burned or piled and burned without injury to the forest.

Since the selection stand contains trees of all ages in mixture, the difficulty of burning slash without injury to the forest is greater than under most other reproduction methods. Broadcast burning cannot be used without destroying the unevenaged forest.

Cuttings under the coppice methods. Utilization is necessarily close in the simple-coppice method of reproduction. The rotation is short, and the largest trees in the stand when cut are relatively small. Only a small amount of slash consisting of small branches and foliage is left after the cutting. This material rots easily and is not abundant enough to smother sprout reproduction. An added reason for allowing the slash to rot on the area rather than burning it up is to prevent deterioration of the soil under coppice management.

Even on the longer coppice rotations the accumulation of slash is not enough to require the expense of slash disposal. In sprout stands of hardwoods the chief fire hazard comes from the inflammable leaf litter and not from the slash. Surface fires serious enough to kill mature trees can develop in hardwood leaf litter. Presence of slash may increase the severity of fires and the difficulty of fighting them, but not sufficiently to justify the expense of disposing of the slash.

Slash disposal after cuttings under the coppice-with-standards method is not advisable for the same reasons.

Intermediate Cuttings. The slash remaining after intermediate cuttings is small, both in size of pieces and in total quantity. Intermediate cuttings cannot be made without the existence of fairly good markets, which in turn permit close utilization. Ordinarily the slash does not require disposal.

In liberation cuttings the slash should be lopped and scattered if

it is lying upon reproduction. Very heavy thinnings, improvement cuttings, or salvage cuttings, particularly in coniferous stands, may create a slash heavy enough to need disposal. Swamper burning or lopping is suggested.

Selecting the Method of Slash Disposal. The total silvicultural effect of slash disposal is a composite of its combined effects upon the soil, upon reproduction, and upon combatting the chief enemies of the forest: fires, insects, and fungi. What is best in slash disposal for one of these may be injurious for another. In other words, in the requirements for treatment of slash to produce the most satisfactory results, these various interests may conflict.

The greatest benefit to the soil usually follows retention of all the slash. Upon reproduction the effect of slash is so variable, being either beneficial or injurious, either insignificant in its influence or the primary factor controlling reproduction, that a generalization is difficult. On the whole, presence of slash is more beneficial than injurious to reproduction, except when compact, deep covering inhibits it.

From the standpoint of forest fires complete removal of the slash, which furnishes a substantial part of the fuel for fires, represents the ideal treatment. Of greatest importance is the removal of the smaller, highly inflammable portions of the slash, whereas the larger pieces can often be safely left.

In the control of insects attacking living timber the method of slash disposal exerts little if any influence. The few species of dangerous insects breeding in the slash inhabit the large pieces (cull logs and butts) which are not ordinarily disposed of. An ideal disposal of slash from the entomological standpoint would require removal of, or peeling bark from, the larger pieces of slash. The results to be secured usually do not justify such action.

Although dangerous fungi may live and fruit upon the slash, only in rare instances, if ever, will the method of slash disposal be determined by the factor of tree disease. In the western white pine type, for example, a broadcast burn would char the larger pieces of slash and as a result cause a decrease in the number of sporophores produced (Weir 1923). Other considerations, however, particularly the effect of a broadcast burn in increasing the fire danger, exercise decisive influence in ruling out broadcast burning as the best method of slash disposal for the western white pine type.

Ultimately in the choice of a method for treating the slash a compromise must be struck between conflicting viewpoints, in such a way as to produce the most favorable total effect. It is evident that

in general the reproduction and fire problems will be the two primary factors determining the disposal most desirable from the production standpoint. In coming to a final decision the financial aspect must receive consideration. Since silviculture aims at the highest production not only quantitatively, but also financially, it follows that cost must always be kept in mind.

Siggers (1935), after studying various methods of slash disposal for shortleaf pine, particularly from the viewpoints of fire, regeneration, and cost, decided that the best practice was to leave the tops just as they fell, with the exception of a small proportion which should be pulled away from standing trees and advance reproduction.

Slash disposal is a relatively expensive item, requiring high actual cash expenditure. Skeels (1927) states that in Montana the method of slash disposal considered silviculturally best may require an expenditure of 10 to more than 50 per cent of the stumpage value of the timber operated. It is possible that it may require a cash expenditure greater than the results secured by disposal of the slash are worth.

Brown (1923) thinks that there is little justification for the expenditures necessary to secure slash disposal in northern New England. Dana (1930), however, suggests for the same region that where dense spruce and fir slash cover the ground it be swamper burned at a cost of $1 to $1.50 per thousand feet, board measure, because of the combined benefits of increasing the area available for production and lowering the fire hazard. Slash so dense as to kill or prevent reproduction for 10 to 20 years will occur on approximately 1.5 per cent of the area for each thousand feet, board measure, cut per acre.

In the heaviest cuttings such disposal may be advisable, but in general the relatively small fire danger and the slight injurious effect of slash on reproduction do not warrant large cash expenditures for slash disposal in northern New England.

Cheyney (1939) protests against expenditures for slash disposal as unjustified by the results to be gained. He speaks particularly of the northern Lake states, but his argument has force for many parts of this country.

There may be compensation, in the cheaper logging or lower costs of fire suppression, which may justify an apparently large expenditure for slash disposal. In the past too little thought has been given to the amount of the expenditure for slash disposal that could be justified on the basis of expectable results. The private operator took the attitude that any expenditure was out of the ques-

tion. The United States Forest Service, quite properly setting the example as the most conservative type of management, may have favored high expenditures for slash disposal.

It has become evident that a middle ground must be sought where the two extremes may meet in agreement on methods of slash disposal, properly combining the financial and ecological factors. In 1924 Larsen and Lowdermilk reached the conclusion that for western white pine stands in Idaho expenditures for slash disposal up to a maximum of $1 per thousand feet, board measure, cut were justified simply as a fire-protective measure, through savings in fire-suppression costs and fire losses. Since this type has an exceptionally high degree of inflammability this figure may be looked upon as the minimum cost that can be justified for fire protection alone. Other silvicultural benefits combined with fire protection might in theory justify a larger expenditure for slash disposal.

With the passage of years specific knowledge has been built up and is constantly increasing as to costs of slash disposal, the good and bad results to be expected from slash disposal, and the possibility of obtaining forest management objectives without large expenditures for the reduction of slash. Today it is doubtful that anyone can justify slash disposal charges of $1 per thousand feet, board measure, of the cut. Can even a charge of 35 cents per thousand be justified by results to be obtained? Probably not, if the administrators who advocate such expenditures are once emancipated from the old habits of thought on the subject of slash disposal.

The cost of slash disposal may be figured either on an acreage basis or by the thousand feet, board measure, of timber cut — ordinarily the more useful mode of expression, since slash disposal after cutting operations may be considered a current logging expense just as properly as items like felling and skidding. When broadcast burning is used the total cost per acre is almost completely independent of the amount of timber cut per acre; in other methods of disposal the cost per acre is in proportion to the amount of timber cut. Since the amount of timber cut per acre varies from less than 1000 to more than 100,000 feet, board measure, the costs of slash disposal (except with broadcast burning) for comparative purposes are commonly expressed on the thousand-board-feet unit basis. This allows of ready change to per acre figures when the amount cut per acre is known.

In order to show comparative costs for different methods, but for use with the same species in the same locality, Table XXI has been drawn up from the data contained in the publication by Munger and

Westveld (1931), which presents the results of a comprehensive study of slash-disposal methods in the ponderosa pine forests of Oregon and Washington. It does not necessarily follow that the same relative difference in cost between methods will hold for other regions and species.

TABLE XXI

Method of Disposal	Costs per M ft. B. M. of Slash Disposal in Stands of Ponderosa Pine in Eastern Oregon and Washington
Complete disposal	
Broadcast burning	Practically nothing; expressed as 1 to 5 cents per acre
Spot burning	1 to 3 cents or 10 to 20 cents per acre
Lopping	20 to 25 cents
Piling and burning	35 to 70 cents; lowest in heavy stands of timber; on the average 45 to 55 cents, of which approximately 5 cents is for burning
Swamper burning	55 to 60 cents; 10 per cent more expensive than piling and burning
Partial disposal	
Piling and burning	8 cents
Intensive fire protection	14 cents or a total of 22 cents where slash is piled and burned on approximately 17 per cent of the area

The cost of slash disposal per thousand feet, board measure, is greater for trees with heavy crowns than for light-crowned trees, for small trees than for large trees, for a light cut per acre than for a heavy cut, and for rough ground than for smooth ground.

As utilization of the upper part of the tree becomes closer the cost of slash disposal decreases. The attitude of the men engaged in the work of slash disposal often affects their efficiency and consequently the cost. Slash disposal is not always accepted willingly by lumbermen as a worth-while and practical operation. They may be disposing of slash because forced to do so by state law or as part of the contract when buying timber from the federal government. Where this attitude prevails it is difficult to dispose of slash cheaply and efficiently.

In general the cost of slash disposal under the different methods described will range from 1 or 2 cents up to $2 per thousand feet, board measure, of timber cut, and from less than $1 to more than $25 per acre. The minimum figures would be attainable under the broadcast burning method with a cut of 50,000 to 100,000 feet, board measure, per acre or in regions of open forests not subject to crown fires. The maximum ought not to be necessary except where, in small rough timber, a method of piling and burning is conducted in a most

thorough manner, or where lopping with careful scattering is employed.

The average costs of slash disposal fall between 35 and 75 cents per thousand feet, board measure. In many instances these costs appear unnecessarily high for the silvicultural results secured. Since complete disposal of the slash by any of the three most promising and widely used slash-disposal methods, namely, piling and burning, swamper burning, and lopping and scattering, is not likely to be accomplished at costs below the average figures given, some substitute for complete slash disposal must be sought if the expenditures are to be lowered. The tendency today is toward the development and use of substitutes for complete disposal.

The most promising field appears to lie in the following combination: first, the development and application of an intensive fire-protection plan for cutover areas during the relatively short period after the logging (5 to 15 years on the average), throughout which the slash constitutes an increased fire hazard; and second, leaving the slash untouched on approximately 80 to 90 per cent of the area, with disposal of slash according to one of the usual methods on the remainder of the area, so selected as to form firebreaks 100 to 200 feet in width and to include the portions having the greatest fire hazard. Koch and Cunningham (1927) for the larch-fir forests in the northern Rocky Mountains, Show (1926) for the California pine region, and Munger and Westveld (1931) for the ponderosa pine forests in eastern Oregon and Washington, all suggest the possibilities of partial slash disposal. The special fire protection may consist of intensive patrol or close oversight by lookout stations with provision for ample fire-fighting equipment, transportation, and personnel.

The total cost of such a partial disposal method where the slash is piled and burned on strips comprising about 17 per cent of the area, including the costs of intensive fire protection for 15 years after cutting, is estimated by Munger and Westveld (1931) to be approximately 22 cents per thousand feet, board measure, of logs cut, divided into 8 cents for slash disposal and approximately 14 cents for fire protection.

In certain types the employment of stock grazing as a means of reducing the fire danger may be so successful as to obviate the need of slash disposal from the protection standpoint. This plan is of relatively limited application and is possible only in forests where the herbaceous material of forage value furnishes the chief fuel for progress of a fire.

The Lake States Forest Experiment Station (Anonymous 1944)

suggests disking cutover jack pine lands with the Athens-type disk harrow as a slash-disposal method. They assert that this operation, usually employed as a method of encouraging regeneration, lowers fire hazard from logging slash to about the same degree as piling and burning the slash. Cost of such disking is estimated at $4.25 to $5.75 per acre.

At the present time several states, among them Idaho, Minnesota, Montana, Oregon, and Washington, have compulsory slash-disposal laws requiring the disposal of slash on logging operations. The result of past experience with slash disposal regulated by law indicates that no one method is going to cover all requirements and that the method of disposal to be applied in each stand is best left to the discretion of the supervising official, who should be the state forester.

In several states the law requires disposal of slash along highways and railroads and in a narrow zone along property boundaries, but not over the entire cutover areas. It seems desirable that in every state the proper forestry official should have the power to declare certain areas a menace from the accumulation of slash left thereon, and to require either proper disposal of the slash or intensive protection until the slash ceases to constitute a special hazard.

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CHAPTER XVI

IN CONCLUSION

The preceding chapters have dealt with both the methods of securing natural and artificial reproduction as the harvesting of mature timber is carried on and the tending of immature forest crops. In the present chapter certain features of the broader aspects of silvicultural policy are discussed.

Undoubtedly, to some foresters the consideration of the various reproduction methods and the intensive application of intermediate cuttings may seem a waste of time, because this country is in such an early stage of forestry practice today. Professional education in forestry within the United States dates back only to the turn of the century. The National Forests have been under professional management since about 1905. Most of the forest area in the country is still without any application of silviculture or else under a very simple form of forest management. The greater portion of the forest area is either virgin timber, situated in the more inaccessible portions of the country, or culled and second-growth forest seriously depleted as to growing stock.

The chief concerns of forestry throughout the country during the last half century have been propaganda to obtain support for the forestry movement, the acquisition of public forests, the establishment of an adequate system of forest-fire control, and the organization of such areas as have become available for timber growing. Where silviculture has been applied on virgin forest areas the chief objectives have been the prevention of losses, particularly from insects, and the harvesting of overmature and mature bodies of timber usually under rather difficult economic conditions. So far, application of silviculture on the culled and second-growth forest areas has necessarily been directed to improvement of the existing forest. This implies building up depleted growing stocks, utilizing the relatively inferior trees and species in the forest, protecting the trees against a wide variety of injurious influences, and harvesting what little mature timber can be spared from inadequate growing stocks.

It should be evident from what has just been said that up to the present time the forest manager, engrossed with urgent problems of

acquisition, organization, protection, and development of timber sales in virgin forests and in previously overcut culled and second-growth forests, has had his hands full without giving much attention to the silvicultural systems (including the methods of obtaining reproduction, of harvesting the mature timber, and of tending the new crops) which will ultimately be introduced.

In most forest areas the task of rebuilding depleted growing stocks will consume many more years, and the transformation from the virgin forest, with its accumulation of decadent trees, to vigorous stands of lower average age will also require a long time. Nevertheless as soon as the first pressing problems of organization, development, and protection have been recognized, and their solution has been planned, it will be a wise policy to consider what type of silvicultural system will best fit the species and economic requirements in a given forest.

The cuttings now being made in the early stages of forest management will leave their impress upon the forest and will strongly influence stand and forest structure. The forester who makes these cuttings more or less haphazardly, without appreciating this fact and attempting to control stand and forest structure to meet ultimately desirable objectives, is not taking full advantage of his opportunities. Present timber-cutting operations can be made useful for the attainment of future planned objectives, if the forester possesses vision and imagination resting on a sound basis of silvicultural principles.

It is not necessary that the objective be the ultimate development of one of the standard reproduction methods as described in the text. These as already stated (page 20) are simply arbitrarily selected points in a wide range of possibilities, within which ecological and economic conditions should determine a development of detailed silvicultural practice exactly suited to the locality and species. However, broad knowledge of theories and principles of silviculture forms an indispensable background for success in this task.

In developing details of a local method for handling the three essentials of forestry practice, as distinguished from simple exploitation of the existing timber stand, namely, harvest of mature timber, establishment of a new crop to replace that harvested, and tending of the new crop throughout its life, both the ecology of the species and the financial aspects of the situation must receive consideration.

The light demands of the species, the characteristics of the seed, and the requirements for germination and establishment of repro-

duction may often determine what methods of reproduction are possible with a given species. On the economic side, the classes of forest products which sell to best advantage may determine whether evenaged or unevenaged production should be employed. A concentration of the cutting operations concerned both with harvesting mature timber and with stand improvement is very desirable from the economic standpoint. This is true both because transportation of forest products will be shortened by concentrating the cuttings, and because of the cheaper and better control of operations obtained by such concentration. This point is as yet rarely appreciated at its full value because, without abundant, good examples of forestry practice, there has been as yet no opportunity to build up adequate experience on this point. When more foresters have actually seen and practiced forestry under both of the contrasting conditions of concentrated and of scattered operations, there will be a swing toward systems of silviculture which feature concentration of cuttings. It requires a more skilled personnel and a closer supervision to obtain equally good results when cuttings are scattered.

The necessity for protection by the forest to the site and the extent to which such protection is required will sometimes be the determining factors in selection of a silvicultural system.

To date in most instances either no system has been in mind, or else a choice has been made largely on the basis of the condition of the forest at the time forestry practice is first applied. This condition is, ordinarily, a factor of only temporary importance, and the immediate treatment dictated by existing forest conditions is essentially of temporary nature and may be looked upon as only preparatory to the introduction later of some silvicultural system that may be applied consistently in the future. The mistake should be avoided of thinking that a currently used, temporary type of treatment can be continued indefinitely.

When this country actually reaches the point where the decadent growing stock in virgin forests has been removed and the culled and second-growth forests have recovered from their present depleted condition, application will probably be made of all the silvicultural systems described in this text. It is likely that the methods of reproduction producing evenaged stands will be used most often, because of the greater simplicity of management and consequent lesser demands on personnel, and because concentration is more efficient than scattered operations.

This statement is made even though there can be discerned today a tendency to favor selection types of cutting. Forestry, like other

lines of business, runs to fads. For some years there has been what might be termed a selection mania. Not all those who are so afflicted know whether they are advocating the production of timber crops in unevenaged or in evenaged stands. In other words they do not have a clear idea of what is meant by selection cuttings. And some, who are clear on this point, have little conception of the practical difficulties involved in making a system of production in unevenaged stands function efficiently.

There are several reasons for the favor gained by selection cutting. One reason is that in a forest composed of middle-aged, second-growth stands the only sawtimber which can be obtained for many years is contained in the comparatively few larger trees. By selectively cutting these larger trees a small yield of sawtimber can immediately be obtained. As a temporary measure to give the owner some revenue while he is building up the growing stock, such a cutting may be allowable, although the growing stock would build up faster if these trees were left. Very little, if any, reproduction will become established as a result of such a cutting, and the stand could be allowed to remain in its present evenaged form until the end of the rotation.

Another reason accounting for the interest in selection cutting is that so much of the forest area needs improvement cuttings. Frequently in such stands some of the larger trees are removed, but emphasis is placed on improvement of the existing stand rather than on reproduction, which is not expected as a result of the cutting. Forests, in which the main problem evidently is to improve the growing stock in quantity and in quality rather than to secure regeneration are in the stage where intermediate cuttings are needed rather than the application of any reproduction method.

Another idea, often held, is that selection cuttings can be repeated in a stand at intervals for an indefinite period without reproduction becoming established, and that the entire area can be kept permanently in timber of merchantable size upon which current growth will be at a maximum. It is a well known fact that current growth, particularly when expressed in feet, board measure, is much higher in the second half of the life cycle of a managed forest crop, because nearly all the growth is laid upon trees already of merchantable size. If the stand could be kept in condition to produce permanently at this high rate, the mean annual production might be more than doubled. It is impossible, however, to attain this ideal. Some areas must be occupied by young growth and reproduction if production is to be maintained. Selection cuttings cannot be continued

indefinitely without systematically turning part of the area over to reproduction.

Undoubtedly the concept of utilizing continuously the period of maximum current growth rate has arisen from a few examples in European countries of highly intensive silviculture which have attracted wide attention. One such example is the forest at Bärenthoren, Germany, which has been much publicized in literature (principally German) since about 1925 and which has been called to the attention of many foresters traveling in Europe. Unfortunately such visitors usually do not read adequately in the literature on the subject and sometimes draw erroneous conclusions from incomplete information. The Bärenthoren forest is an example of the so-called "*Dauerwaldwirtschaft*" or "continuous forest management" discussed on page 157. The forest has been managed for about half a century by frequent and light cuttings best described as thinnings. Much has been said, in describing the forest, about there being little emphasis on reproduction and no rotation age. Sometimes this has been interpreted as evidence that it is unnecessary to give consideration to reproduction and that the old idea of a rotation age was meaningless.

Actually, the Bärenthoren forest at the time the management started was a young to middle-aged forest and not in the stage of its life development where anything but intermediate cuttings were needed. The forest illustrates the value of systematic thinnings and careful tending of the stand. Consequently no attention was given to reproduction. Now after a half century of systematic thinning the forest has reached the period in life when reproduction is wanted and ultimately the old stand will be removed. The management may be considered an example of shelterwood with a long period of regeneration and a rotation probably of about 120 years.

Another classic example of an intensively managed forest is the small communal forest of Couvet in Switzerland where Biolley developed his continuous inventory system. The details of this system will not be discussed here; the idea brought up for comment is that this forest illustrates a selection type of management with little or no consideration for reproduction. If what the author saw during a brief inspection of a portion of the Couvet forest under Biolley's guidance was a fair sample, the forest form was more regular than unevenaged with a great preponderance of the older class of trees, evidencing probably a former evenaged condition. Here again a half century of intensive treatment as at Bärenthoren had resulted in a highly productive forest. The impression made on the observer

was more that of a dense forest of shade-enduring species with a high growing stock, relatively regular in form and not yet opened up for reproduction, and quite unconvincing as an application of the selection system.

These forests, Bärenthoren in particular, illustrates what fine results can be secured from light, frequent cuttings started in stands of regular form, before or at middle age, and carried on for many decades without thought of reproduction or of a fixed rotation age. Sooner or later the time comes when reproduction takes an appropriate share of the space. The average age at which trees become ripe for harvest can be determined, even though the time of their cutting may be based on desired sizes obtained and growth capacity rather than on actual age. Rotation age should not be thought of and applied as a rigid age limit for cutting.

The statement is ventured that nowhere yet, even in European practice, has it been proved that a forest area can be kept indefinitely in large timber alone and still harvest indefinitely an annual production approximately equal to the current growth of an evenaged stand during the period of its highest production. It can be done for a while by starting with a forest area entirely occupied by middle-aged stands, but it can be continued only until these stands mature. No, it is impossible to have your cake and eat it too.

The old idea that for continuous production you must have approximately equal areas occupied by trees of a range of ages adequate to cover the span of the desired rotation is still sound. Intensive tending of stands can undoubtedly prolong the period during which individual trees are profitable items of the growing stock, but finally they become unprofitable and must be removed. When this time comes, the space which they have occupied will have to be turned over to reproduction. The larger the area once held in large trees, the larger will be the area now in reproduction.

Intensive tending of the nature we have been discussing, sometimes termed single-tree management, requires excellent facilities for extraction of forest products, good markets for their sale, and in addition a skilled personnel both for the harvesting operations and for the calculation and marking of the annual cut. Very rarely in this country is the combination of all these factors available, which makes it difficult or even impossible under our present stage of development to undertake the intensive single-tree type of management. Small tracts furnish the best opportunities.

The term "selection cutting," as frequently used in Europe, applies more aptly to the intensive tending of stands relatively regular

in form than to cuttings which maintain unevenaged stand structure.

The selection mania carries as a corollary condemnation of clear-cutting as a practice destructive of the forest, injurious to the soil, and financially less profitable than selection or any kind of partial cutting. Those who hold this viewpoint apparently think that clear-cutting requires cutting clean large areas of forest at one time and place. Nothing could be farther from the truth. The clearcutting system does not necessarily involve clearing off the whole tract in a relatively short time. Clearcuttings can be so small in size, and so interspersed among areas of uncut forest, as to appear similar to the groups created under application of group selection. In fact the two methods may approach each other so closely as to be difficult of separation. The opponents of clearcutting often seem to infer that no intermediate cuttings are made during the life of the crop. They fail to appreciate that intensive tending of the stand can be carried on in forests managed under the clearcutting system. Where such tending in the later half of the rotation opens the stand enough to permit establishment of reproduction, the clearcutting method merges into shelterwood; the difference between the two methods, when each is intensively applied, is the more gradual harvesting of the old stand under shelterwood and the appearance in clearcutting of the major part of the regeneration after, rather than before, removal of all the old stand.

This discussion is not an argument against selection cutting or for clearcutting. Each has its good points and its drawbacks. The position taken is that all reproduction methods have their place and will be found appropriate under certain circumstances. We may be sure, when once the transition period during which forests are organized and built up is past, that standard reproduction methods will be employed. Clearcutting, two- or three-cut shelterwood, and group selection are the ones most likely to find wide application. The highly intensive modifications of shelterwood and selection, usually occupying an intermediate place between these two methods, and now so much of a forestry fad, are too advanced for the stage of forestry at present characteristic of this country. In applying silviculture it will, for the time being, be best to center efforts on simple methods, leaving the more intricate and refined to come later, when managed forests become the rule rather than the rare exception, and when thoroughly trained and experienced personnel become available in adequate numbers.

APPENDIX

Common and Technical Names of Tree Species Mentioned in the Text

Common Name	Technical Name
Ash, white	*Fraxinus americana*
Aspens	*Populus* sp.
Beech (European)	*Fagus sylvatica*
Birch, paper	*Betula papyrifera*
Chestnut, American	*Castanea dentata*
Cottonwood	*Populus deltoides*
Douglas-fir	*Pseudotsuga taxifolia*
Fir, alpine	*Abies lasiocarpa*
balsam	*Abies balsamea*
grand	*Abies grandis*
silver (European)	*Abies pectinata*
Hemlock, eastern	*Tsuga canadensis*
western	*Tsuga heterophylla*
Hop-hornbeam	*Ostrya virginiana*
Larch, western	*Larix occidentalis*
Locust, black	*Robinia pseudoacacia*
Maple, red	*Acer rubrum*
sugar	*Acer saccharum*
Oak, bear	*Quercus ilicifolia*
red	*Quercus borealis* and *Quercus borealis maxima*
white	*Quercus alba*
Pine, eastern white	*Pinus strobus*
jack	*Pinus banksiana*
jelecote	*Pinus patula*
loblolly	*Pinus taeda*
lodgepole	*Pinus contorta latifolia*
longleaf	*Pinus palustris*
pitch	*Pinus rigida*
ponderosa	*Pinus ponderosa*
Monterey	*Pinus insignis*
red	*Pinus resinosa*
Scotch	*Pinus sylvestris*
shortleaf	*Pinus echinata*
slash	*Pinus caribaea*
sugar	*Pinus lambertiana*
Virginia	*Pinus virginiana*
western white	*Pinus monticola*

Common Name	Technical Name
Redcedar, western	*Thuja plicata*
Redwood	*Sequoia sempervirens*
Spruce, black	*Picea mariana*
Engelmann	*Picea engelmannii*
Norway	*Picea excelsa*
red	*Picea rubra*
Sitka	*Picea sitchensis*
white	*Picea glauca*
Sweetgum	*Liquidambar styraciflua*
Teak	*Tectona grandis*
Wattle, black	*Acacia mollissima*
White-cedar, Atlantic	*Chamaecyparis thyoides*
Port Orford	*Chamaecyparis lawsoniana*
Yellowpoplar	*Liriodendron tulipifera*

INDEX

H

I

J

K

L

R

S

U

V

W

Y

Z